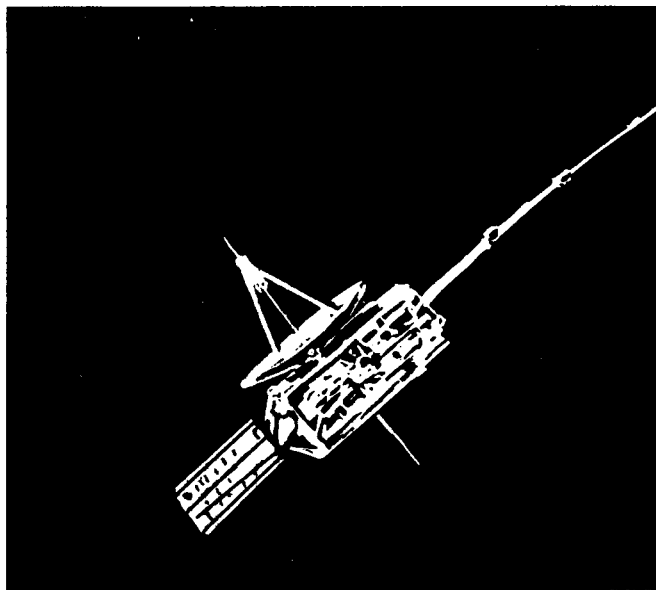
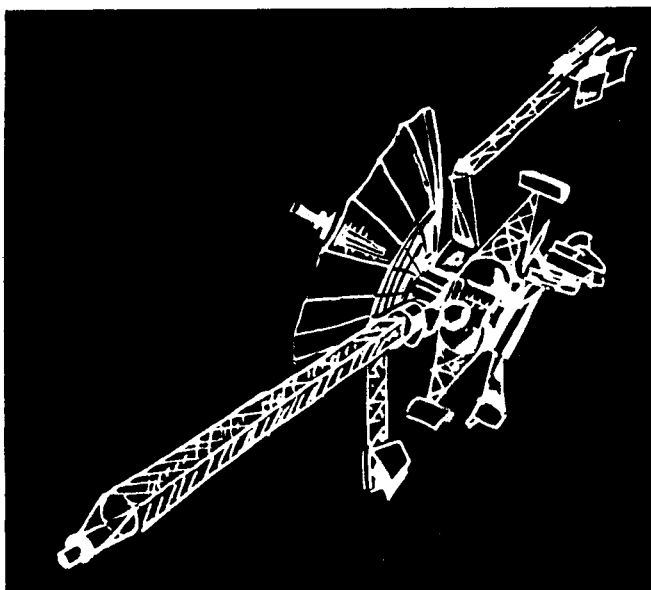




National Aeronautics and
Space Administration

November 1988

Final (Tier 1) Environmental Impact Statement for the Galileo and Ulysses Missions



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National Aeronautics and
Space Administration

Final (Tier 1) Environmental Impact Statement for the Galileo and Ulysses Missions

**Office of Space Science and Applications
Solar System Exploration Division
Washington, D.C. 20546**

November 1988

ABSTRACT

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This document is a Final (Tier I) Environmental Impact Statement (EIS) addressing the potential environmental consequences associated with continuing the modifications of the Galileo and Ulysses spacecraft for launch using a booster/upper stage combination that is different from the one planned for use prior to the Challenger accident, while conducting the detailed safety and environmental analysis in order to preserve the October 1989 launch opportunity for Galileo and an October 1990 launch opportunity for Ulysses.

While detailed safety and environmental analyses associated with the missions are underway, they currently are not complete. Nevertheless, sufficient information is available to enable a choice among the reconfiguration alternatives presented. Relevant assessments of the potential for environmental impacts are presented.

SUMMARY

The Galileo and Ulysses missions are part of the National Aeronautics and Space Administration's (NASA's) Solar System Exploration Program. The Galileo mission is designed to study Jupiter, its four major moons, and its extended electromagnetic environment. The Ulysses mission is a joint program of the European Space Agency (ESA) and NASA and is designed to study the polar regions of the Sun.

PURPOSE AND NEED FOR THE ACTION

The proposed action addressed by this Final (Tier 1) Environmental Impact Statement (EIS) is to continue with modifications to the Galileo and Ulysses missions as currently planned. This EIS has been prepared to provide updated information necessary to support decisionmaking associated with continuing to make modifications to the Galileo and Ulysses spacecraft to preserve the launch opportunity on the Space Transportation System (STS) Shuttle in October 1989 and October 1990, respectively. NASA previously had planned to use the Shuttle and the newly designed Centaur G-Prime upper stage rocket for launching both missions in May 1986. A Draft EIS for this configuration previously was published in September 1985. Following the Challenger accident, NASA cancelled the development of the Shuttle version of Centaur (i.e., the Centaur G-Prime) due to safety concerns unrelated to the Galileo and Ulysses spacecraft. This action has required NASA to define and select a new booster/upper stage combination for both the Galileo and Ulysses missions, and to prepare this Final (Tier 1) EIS.

Additional National Environmental Policy Act (NEPA) related documentation will address the proposed action of the completion of the development and operation of the missions, including their launch using the Shuttle/IUS launch vehicle configuration. The additional NEPA documentation will utilize the most pertinent data and analyses directly related to the missions which will result from extensive safety test and analysis programs currently being conducted by NASA and the U.S. Department of Energy (DOE).

The modifications of the spacecraft addressed in this EIS are necessary to allow the missions to accomplish their scientific objectives at minimum cost of scarce human and fiscal resources. The proposed action is to continue modifying the existing spacecraft; performing the work required to integrate the spacecraft with the new launch vehicle; and conducting supporting design, test, and development efforts, while completing the Final Safety Analysis Report (FSAR) and the additional NEPA related documentation addressing launch implications. This action is necessary to preserve the option of launch of the Galileo and Ulysses spacecraft in October 1989 and October 1990, respectively. Any delay in the launch will increase costs, delay scientific returns, threaten further loss of key personnel, and threaten the performance of spacecraft systems due to shelf-life deterioration.

At NASA's request, the DOE is participating in the preparation of this EIS because of its role in providing Radioisotope Thermoelectric Generators

(RTGs) and Radioisotope Heater Units (RHUs) for NASA missions and because of its responsibility for RTG and RHU applications.

In addition to the requirements of the NEPA, missions such as Galileo and Ulysses, which involve radiological material, must satisfy an extensive interagency launch safety approval process which involves the Interagency Nuclear Safety Review Panel (INSRP) and the Office of Science and Technology Policy (OSTP). The OSTP bases its decision on the Agency's request, the supporting positions by the DOE and DOD, and the INSRP SER. The approval process is set forth in NSC-PD 25 (December 14, 1978) which documents the steps followed by the agencies (DOE, NASA, DOD) since the early 1960's. The agency proposing to launch a mission is required to conduct an extensive safety analysis prior to requesting launch approval from the OSTP. In the present case, DOE conducts the safety verification test and analysis activity for NASA because DOE retains ownership of, and responsibility for, the nuclear systems even though they are integrated onto the NASA spacecraft. DOE provides NASA and the INSRP with a FSAR. The INSRP coordinates the independent safety evaluations by the safety and environmental elements of the agencies and provides a Safety Evaluation Report (SER) to the agencies and the OSTP. The INSRP consists of coordinators appointed by NASA, DOE, and DOD; INSRP is supported by several expert subpanels. Based on the FSAR, the SER, and consultation with other agencies, the launching agency (i.e., NASA) requests launch approval from the OSTP.

The actual NASA decision to request OSTP launch approval for Galileo will be made in the summer of 1989 and for Ulysses in 1990. The proposed action of this Final (Tier 1) EIS neither precludes nor obviates the opportunity to delay or to cancel the missions at those times.

ALTERNATIVES CONSIDERED

The proposed action addressed by this EIS is to continue to make modifications to the Galileo and Ulysses spacecraft to use the STS with an IUS in place of the Centaur G-Prime upper stage and adopting the Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory for Galileo. This will allow the launch opportunity for the Galileo spacecraft in October 1989 to be preserved while conducting detailed safety and environmental analyses, and also will allow the necessary up-front IUS integration activities for the Ulysses launch planned in 1990 to be performed in a timely, programmatically sound manner. The alternatives to the proposed action discussed in this EIS are:

- Delay the program, including stopping modifications to the spacecraft, until the Safety Analysis Report (SAR) and the additional NEPA documentation for Galileo and Ulysses are complete, precluding a launch of Galileo in 1989 but still allowing a Ulysses launch in 1990 (or 1991 for both spacecraft), and using the same or the Titan IV launch vehicle configuration.
- Continue with either the Galileo or Ulysses mission and cancel the other mission.
- Adopt the no-action alternative, resulting in termination of the further commitment of resources to both missions.

ENVIRONMENTAL CONSEQUENCES

No immediate or near-term adverse environmental consequences are associated with the proposed action to continue spacecraft modifications. The delay alternative also has no environmental consequences. In addition, preliminary review of the environmental risks associated with completion and operation of the missions does not establish a basis either for abandoning or delaying the program. On the other hand, adoption of the proposed action avoids an increase in costs, preserves the schedule for scientific returns, prevents the threat of further loss of key personnel, and lessens the threat to performance of spacecraft systems due to shelf-life deterioration.

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1. PURPOSE AND NEED FOR ACTION

The Galileo and Ulysses missions are part of the National Aeronautics and Space Administration's (NASA's) Solar System Exploration Program. The Galileo mission is designed to study Jupiter, its four major moons, and its extended electromagnetic environment. The Ulysses mission is a joint program of the European Space Agency (ESA) and NASA and is designed to study the polar regions of the Sun.

This Final (Tier 1) Environmental Impact Statement (EIS) has been prepared to provide updated information necessary to support decisionmaking associated with preparing the Galileo and Ulysses spacecraft for a possible launch on the Space Transportation System (STS) Shuttle in October 1989 and October 1990, respectively. The proposed action addressed by this EIS is to continue to make modifications to the Galileo and Ulysses spacecraft to use the STS with the Inertial Upper Stage (IUS) in place of the Centaur G-Prime upper stage and adopting the Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory for Galileo. This will allow the launch opportunity for the Galileo spacecraft in October 1989 to be preserved while conducting a detailed safety and environmental analysis, and also will allow the necessary up-front IUS integration activities for the Ulysses launch planned in 1990 to be performed in a timely, programmatically sound manner. Additional National Environmental Policy Act (NEPA) related documentation incorporating safety data currently being produced and analyzed will be prepared prior to the decision to complete the development and operate the missions.

1.1 BACKGROUND

In September 1985, NASA published a Draft EIS (Ref. 1) for the Galileo and Ulysses missions. The proposed action presented in the Draft EIS was to use the Shuttle and the newly designed Centaur G-Prime upper stage rocket for launching both missions in May 1986. Following the Challenger (STS-51L) accident, NASA cancelled the development of the Shuttle version of Centaur (i.e., the Centaur G-Prime) due to safety concerns unrelated to the Galileo and Ulysses spacecraft. This action has required NASA to define and select a new booster¹/upper stage combination for both the Galileo and Ulysses missions, and to prepare this Final (Tier 1) EIS.

At NASA's request, the Department of Energy (DOE) is participating in the preparation of this EIS because of its role in providing Radioisotope Thermoelectric Generators (RTGs) and Radioisotope Heater Units (RHUs) for NASA missions and because of its responsibility for RTG and RHU applications.

¹For the purpose of this document, the term "booster" will apply to the portion of the launch configuration required to reach Earth orbit. In the case of the STS/IUS launch vehicle configuration the Shuttle serves as the booster and delivers the IUS and spacecraft into orbit. The IUS upper stages then supply energy to place the spacecraft on an interplanetary trajectory (e.g., to Venus or to Jupiter).

In addition to the requirements of the NEPA, missions such as Galileo and Ulysses, which involve radiological material, must satisfy an extensive interagency launch safety approval process which involves the Interagency Nuclear Safety Review Panel (INSRP) and the Office of Science and Technology Policy (OSTP). The approval process is set forth in NSC-PD 25 (December 14, 1978) which documents the steps followed by the agencies (DOE, NASA, DOD) since the early 1960's. The agency proposing to launch a mission is required to conduct an extensive safety analysis prior to requesting launch approval from the OSTP. In the present case, DOE conducts the safety verification test and analysis activity for NASA because DOE retains ownership of, and responsibility for, the nuclear power systems even though they are integrated onto the NASA spacecraft. DOE provides NASA and the INSRP with a Final Safety Analysis Report (FSAR). The INSRP coordinates the independent safety evaluation by the safety and environmental elements of the agencies and provides a Safety Evaluation Report (SER) to the agencies and the OSTP. The INSRP consists of coordinators appointed by NASA, DOE, and DOD; INSRP is supported by several expert subpanels. Based on the FSAR, the SER, and consultation with other agencies, the launching agency (i.e., NASA) requests launch approval from the OSTP.

The actual NASA decision to request OSTP launch approval for Galileo will be made in the summer of 1989 and for Ulysses in 1990. The proposed action of this Final (Tier 1) EIS neither precludes nor obviates the opportunity to delay or to cancel the missions at those times.

The Galileo and Ulysses missions support NASA's Solar System Exploration Program and its continuing responsibility to engage in the scientific exploration of the solar system using Earth-based observations, spacecraft, laboratory studies, and theoretical research. The goals of this program are to further our understanding of:

- The origin and evolution of the Solar System
- The origin and evolution of life
- The Earth by comparative studies of the other planets.

The Galileo and Ulysses missions are expected to make important contributions toward these goals.

1.1.1 Galileo Mission

The scientific objectives of the Galileo mission are to conduct comprehensive investigations of the Jovian planetary system by making measurements of the planet, its environment, and its satellites. Jupiter is the largest and most massive planet in the solar system, and is unique in that it emits more energy than it receives. Together with its moons, the planet almost comprises a mini solar system. Close-up studies of the planet and its principal satellites will greatly extend the knowledge of the role of the Jovian system in the complex and analogous relationships existing between the Sun and its planetary system.

The Galileo objectives will be accomplished through two separate mission elements:

- An orbiter will tour and study the planet and the Jovian satellites over a 20-month period
- A detachable atmospheric entry probe will descend through the atmosphere of Jupiter and during a period of roughly 1 hour relay scientific measurements of the atmospheric profile to Earth via the orbiter.

The Galileo mission will be a study of the entire Jovian system, with scientific objectives that fall into three broad categories: (1) the structure and composition of Jupiter's atmosphere; (2) the composition and physical state of the Galilean satellites; and (3) the structure, composition, and dynamics of the Jovian magnetosphere.

Previous missions to Jupiter have made only remote measurements of the Jovian atmosphere. It is believed that Jupiter is composed of the original material from which stars, and most specifically our Sun, are formed. The atmospheric entry probe should provide data, during a 1-hour atmospheric descent period, on the Jovian atmospheric composition to a depth of 10 to 20 times the sea-level pressure on Earth. It is anticipated that this will include all the major cloud layers of the Jovian atmosphere. This will greatly enhance the present understanding of the Jovian atmosphere, and of planetary atmospheres in general. It may be possible to acquire knowledge of the conditions in the solar system at the time of planetary formation. The abundance of helium and rare gases in the Jovian atmosphere are important indicators of conditions in the early solar system and of how the giant planets kept their atmospheres. It is possible that the outer Jovian atmosphere is representative of the unmodified material that subsequently formed the Sun, the planets, and other solar system objects. Other information that will be obtained from the atmospheric entry probe includes the location and characterization of the Jovian clouds, an analysis of how solar energy is absorbed and the quantity of energy that is flowing out of Jupiter's still-cooling interior, a determination of lightning frequency, and a determination of whether or not small quantities of organic molecules are being created from methane and ammonia.

The 20-month period during which the orbiter will be obtaining information while in orbit around Jupiter will provide new information on the deep interior of Jupiter through measurements of the Jovian gravitational field.

The Jovian satellites will be investigated at ranges from 20 to 100 times closer than earlier missions, typically at ranges of 1,000 km or less. This proximity will permit images of 20 meters resolution that are comparable to the Viking imagery of Mars. This increased resolution will result in new and detailed knowledge of the surfaces of the satellites, including extremely interesting features such as the active volcanoes of Io, the innermost of the four Jovian satellites. It should be possible to determine the composition, temperature, and activity of Io's volcanic plumes

and volcanic flows over the duration of the orbital investigations. In a manner similar to the investigation of the interior of Jupiter, gravitation data may determine whether Io has a completely molten core, as some theories suggest.

The Jovian magnetosphere is the region of space under the dominant influence of Jupiter's magnetic field. It is an immense structure that, if visible from Earth, would appear several times larger than the full moon. The results of brief flyby measurements of four previous spacecraft have determined that the Jovian magnetosphere is much more complex and dynamic than had been anticipated from Earth-based measurements and theoretical extrapolations from the Earth's magnetosphere. The outer regions of the Jovian magnetosphere expand and contract by millions of kilometers in response to solar wind and internal forces. (The solar wind comprises the magnetic fields, protons (hydrogen nuclei), electrons, and ions of other elements from the Sun.) The inner regions of the Jovian magnetosphere are influenced by Jupiter's rapid spin (one revolution each 10 hours) and by the large quantities of sulfur and oxygen atoms emanating from Io. Jupiter also is a "laboratory" for studying phenomena applicable to other astrophysical objects and to processes of ionized gases in general. The Galileo mission will explore these phenomena with new and more sophisticated instrumentation. Furthermore, the investigations of this dynamic environment will extend over nearly 2 years. New regions of the outer magnetosphere will be explored, as well as repeated penetrations into the inner regions. The mission will include at least one long orbit into the "magnetotail," a distended, cone-shaped region formed as the solar wind sweeps the magnetic field back away from the planet. This mission will provide the results of measurements which, in detail and specificity, can not conceivably be made from Earth or from Earth orbit.

1.1.2 Ulysses Mission

The scientific objectives for the Ulysses mission are to conduct studies of the Sun and the heliosphere (i.e., the regions of space for which the Sun provides the primary influence) over a wide and unexplored range of heliographic latitudes. The Sun controls the Earth's environment to such an extent that small changes in solar conditions can have a measurable effect upon the Earth's climate. The Sun is the nearest star, and thus provides direct information on stellar phenomena. The Sun and its heliosphere constitute a giant astrophysical laboratory that can provide information on the behavior and interaction of magnetic fields, ionized gases, and energetic particles.

All previous spacecraft that have studied the Sun and the heliosphere have done so in, or near, the ecliptic plane. (The ecliptic plane is the plane in which the Earth and other planets orbit the Sun.) Because of the structure and dynamics of the Sun's magnetic field and its solar wind, it is anticipated that fundamentally different phenomena will be observed in the polar regions (high heliographic latitudes). Even some phenomena at intermediate heliographic latitudes are expected to be different from either the ecliptic or polar regions. Also, due to the solar rotation period of approximately 27 days, all long-term phenomena on the solar surface are obscured from view half the time; this will not be true for viewing from the

polar regions. The Ulysses spacecraft, by flying over the polar regions of the Sun, will provide unique data that will increase the scientific knowledge of the Sun and the heliosphere.

The principal scientific areas of study for the Ulysses mission are the solar corona (the Sun's outer atmosphere), the solar wind, the magnetic field, solar and non-solar cosmic rays, and interstellar and interplanetary neutral gas and dust. Other scientific areas also will be studied.

The complex interaction of the Sun's magnetic field, and its solar wind in the heliosphere, concentrate most of the activity and influence on other phenomena to low heliographic latitudes about the ecliptic. Out of this region, other astrophysical phenomena can be observed. For example, cosmic rays, which are energetic particles, consisting primarily of hydrogen and helium nuclei, and also some nuclei of heavier elements. Solar-produced cosmic rays are slowed down by the solar wind. Non-solar cosmic rays arriving from other parts of the galaxy have their low-energy components swept away by the solar wind. At high heliographic latitudes, these solar and non-solar cosmic rays will be observed in a relatively undisturbed state.

The study of the Sun's corona from high heliographic latitudes will be important because not all of the corona's properties can be observed from the plane of the ecliptic. New information will be obtained on other properties of the sun, including solar flares, solar radio noise, and solar x-rays.

Helium particles are an important source of information on the state of the interstellar gas in the vicinity of the solar system, but they are extremely difficult to detect. The Ulysses spacecraft has been designed to make the first direct measurements of neutral helium in the heliosphere. Measurements of dust particles throughout the heliosphere will provide information on how circumstellar dust clouds develop.

Gamma rays are photons with extremely high energies compared to visible light, ultraviolet light, or x-rays, and usually result from large astrophysical phenomena. By triangulating gamma ray bursts over long distance baseline detectors, scientists will be able to locate the sources of cosmic gamma ray bursts. The Ulysses trajectory will provide such a long distance baseline using the Ulysses gamma ray detectors.

Einstein's Theory of General Relativity predicts the existence of gravitational waves in space. These gravitational waves may be caused by the collapse of stars or other astrophysical objects into massive black holes. Analyses of trajectory data from the Ulysses mission may detect such gravitational waves.

The Ulysses trajectory and spacecraft science instruments permit several secondary mission objectives, including the investigation of the space environment between the planets, and a study of the space environment contained within the magnetic field of Jupiter.

1.2 PURPOSE OF THE PROPOSED ACTION

The purpose of the proposed action is to continue modifications to the Galileo and Ulysses spacecraft and use the STS/IUS launch vehicle configuration to preserve the option of 1989 and 1990 launches. These modifications are to enable the replacement of the Centaur G-Prime upper stage originally planned for the 1986 launch.

1.3 NEED FOR THE ACTION

Planetary missions can be launched only at limited times when the planets are aligned appropriately. These alignments are called "launch windows" and occur at approximately 18-month intervals for Galileo and 13-month intervals for Ulysses. If a launch window is missed, then serious adverse cost and programmatic impacts result.

The modifications of the spacecraft addressed in this EIS are necessary to allow the missions to accomplish their scientific objectives as presently scheduled. The proposed action is to continue with modifications to the Galileo and Ulysses spacecraft to use the STS with the IUS while conducting the detailed safety and environmental analyses. This action is necessary to preserve the launch opportunity for the Galileo and Ulysses spacecraft in October 1989 and October 1990, respectively. Any delay in the launch will increase costs, delay scientific returns, threaten further loss of key personnel, and threaten the performance of spacecraft systems due to shelf-life deterioration of spacecraft components.

2. ALTERNATIVES INCLUDING THE PROPOSED ACTION

This Final (Tier 1) Environmental Impact Statement (EIS) addresses the possible environmental impacts associated with proceeding with modifications to the Galileo and Ulysses spacecraft to maintain their launch opportunities in October 1989 and October 1990, respectively. Additional National Environmental Policy Act (NEPA) related documentation will be prepared for each mission using detailed safety and environmental data from the safety verification test and analysis activities. These analyses will evaluate the environmental implications associated with the completion and operation of each mission.

2.1 ALTERNATIVES CONSIDERED

This section of this Final (Tier 1) EIS discusses the following program alternatives available to decisionmakers:

- Continue with modifications to the Galileo and Ulysses spacecraft to use the STS with the IUS in place of the Centaur G-Prime upper stage and adopting the Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory for the Galileo mission. This will allow the launch opportunity for the Galileo spacecraft in October 1989 to be preserved while conducting detailed safety and environmental analyses, and also will allow the necessary up-front IUS integration activities for the Ulysses launch planned in 1990 to be performed in a timely, programmatically sound manner.
- Delay the program, including stopping modifications to the spacecraft, until the Safety Analysis Report (SAR) and the additional NEPA related documentation for completion and operation of the missions are completed, precluding a launch of Galileo in 1989 but still allowing a Ulysses launch in 1990 (or 1991 for both spacecraft), and using the STS or the Titan IV launch vehicle configuration.
- Continue with either the Galileo or Ulysses mission and cancel the other mission.
- Adopt the no-action alternative, resulting in termination of the further commitment of resources to both missions.

2.2 DESCRIPTION OF THE PROPOSED ACTION TO CONTINUE AS PLANNED WITH MODIFICATIONS OF THE SPACECRAFT TO PRESERVE A LAUNCH OPPORTUNITY IN 1989 FOR GALILEO AND 1990 FOR ULYSSES

The change in the upper stage will require a change in the flight trajectory for the Galileo mission from that of a direct flight to Jupiter to the VEEGA trajectory, as described later in this section.

2.2.1 Proposed Modifications to the Galileo and Ulysses Missions

2.2.1.1 Galileo Mission Modifications

Overview of Mission Modifications

The Galileo mission previously was scheduled for launch in May 1986. The spacecraft was to travel on a direct trajectory to Jupiter, where it would arrive in approximately 30 months. Following the January 1986 Challenger accident, NASA rescheduled the mission for launch in October 1989, the earliest available launch window consistent with resumption of Shuttle flight activities. On June 20, 1986, NASA cancelled development of the Shuttle Centaur for safety reasons unrelated to Galileo. The cancellation of the Centaur required a change of upper stage and a new trajectory. Because of the change in trajectory, a number of modifications were required for the spacecraft. The launch vehicle, spacecraft, and trajectory changes relevant to potential environmental impact concerns are discussed below.

Launch Vehicle Change

With cancellation of the Centaur upper stage for the STS, NASA decided to replace the liquid-fueled Centaur with the IUS solid-fueled upper stage. The environmental impacts of the IUS relative to the Centaur when transported on board the shuttle vehicle are currently being assessed. In general, though, it is likely that the accident probability for the IUS is less than that for the Centaur, and the accident environment for the STS/IUS is less severe than that for the STS/Centaur, as the solid fuel is more inert than the liquid oxygen/liquid hydrogen used in the Centaur.

Spacecraft Modifications

Three changes in the Galileo mission have necessitated modifications to the design of the spacecraft. These changes include launching in late October 1989 (vice, May 1986), using the VEEGA flyby trajectory, and using the IUS upper stage booster. The functional areas affected by these changes include: configuration, thermal control, mechanical devices, structure, cabling, power margin, telecommunications, navigation, and attitude control. The new design requirements will necessitate the following:

- Altering the spacecraft configuration to accommodate the addition of VEEGA-related hardware and to accommodate IUS integration
- Making the spacecraft compatible with new thermal environment requirements relating to Venus' proximity to the Sun (0.69 astronomical units), Earth radiation, meteoroids, and the STS/IUS vehicle
- Making the mission compatible with lower telecommunication link margins for mission/navigation, spacecraft characterization,

anomaly investigation, and normal performance evaluation and assessment

- Making the mission compatible with lower power margins.

Of the specific spacecraft changes made in these various areas (see Ref. 2 for additional details), only the addition of Radioisotope Heater Units (RHUs) and another retropulsion module (RPM) heater circuit could influence the potential environmental impacts of the mission; none of the other spacecraft modifications have any significant near-term or long-term environmental impacts.

To maintain a spacecraft power margin, RHUs are being added to the spacecraft in partial replacement of using electrical power for generating heat. The total number of 1 Watt RHUs on board the spacecraft will increase from 103 to 130. Each RHU will have 31.5 Curies of plutonium in the form of a plutonium dioxide ceramic at time of launch¹.

The potential for environmental impacts associated with a launch-abort landing also have been decreased for postulated accidents involving overheating and subsequent explosion of the RPM's propellant tanks. The system for shutting down the RPM heaters powered by the Radioisotope Thermoelectric Generators (RTGs) has been made less susceptible to failure by adding a second circuit to the spacecraft. In the event of an abort-landing, two different circuits exist that can shut down the RPM heaters. This modification substantially decreases the probability of propellant tank overheating. Studies are underway to evaluate the pre-deployment of ground cooling units at abort landing sites to satisfy post-landing safety requirements. Other alternatives also are being considered.

2.2.1.2 Ulysses Mission Modifications

Overview of Mission Modifications

The Ulysses mission previously was scheduled for launch in May 1986 aboard the STS/Centaur. NASA is now planning to launch the mission in 1990 using the STS/IUS with an additional Payload Assist Module (PAM-S) stage. Besides this change in launch vehicle, the Ulysses mission plans no spacecraft or trajectory changes that could influence the potential environmental impacts of the mission.

Launch Vehicle Modifications

The potential changes in the Ulysses mission relevant to the IUS are discussed above. The PAM-S possible accident environments and probabilities are currently under review.

¹The RHUs each will have 31.5 Curies of plutonium at time of launch, assuming the launch will be in 1989. If the launch is in 1990, the RHUs will have 31.2 Curies. The Curies levels for each RTG at time of launch will be 135,000 for 1989 and 134,000 for 1990. These estimates do not include the Curie levels of daughter products.

Spacecraft Modifications

Except for minor changes associated with adapters and mounting brackets, no modifications are required for the spacecraft.

2.2.2 Mission Description

2.2.2.1 Galileo Mission

The Galileo spacecraft consists of an orbiter and an atmospheric entry probe. No combination of launch vehicles presently available to NASA has the capability to place the Galileo spacecraft on a direct trajectory from Earth to Jupiter. Therefore, the Galileo spacecraft will be launched toward Venus where it will execute a flyby maneuver and head back toward the Earth. It will then fly by the Earth twice in order to gain sufficient energy to reach Jupiter. These flybys use the gravitational fields of Earth and Venus to gain sufficient velocity to proceed to Jupiter. Figure 2-1 illustrates the Galileo spacecraft trajectory. After arriving at Jupiter, the orbiter will fly by the moon Io prior to orbiting Jupiter and its moons. The orbiter will conduct a study of Jupiter's atmosphere and the characteristics of the space environment surrounding Jupiter. The atmospheric entry probe, which is to be released prior to the arrival of the orbiter at Jupiter, will descend into Jupiter's atmosphere. During the descent, scientific measurements will be made to determine the structure and composition of the Jovian atmosphere. The data will be relayed to Earth by the orbiter.

2.2.2.2 Ulysses Mission

The Ulysses mission is a joint effort conducted by the European Space Agency (ESA) and NASA. ESA is responsible for developing and operating the spacecraft and for about half of the experiments conducted during the mission. NASA is responsible for providing the launch by the STS/IUS/PAM-S, the remaining experiments, and mission support using the communications and spacecraft tracking facilities of NASA's Deep Space Network.

No combination of launch vehicles available to NASA has the capability to launch the spacecraft on a trajectory from Earth directly over the Sun's poles. Therefore, Ulysses will first fly to Jupiter to use the gravity of the planet to gain speed and subsequently turn back and head out of the ecliptic plane toward the polar regions of the Sun. Since Ulysses is a substantially smaller spacecraft than Galileo (approximately 800 lbs for Ulysses vs approximately 6,000 lbs for Galileo), the IUS can generate sufficient velocity to enable a direct flight to Jupiter. Figure 2-2 illustrates the trajectory of the Ulysses spacecraft.

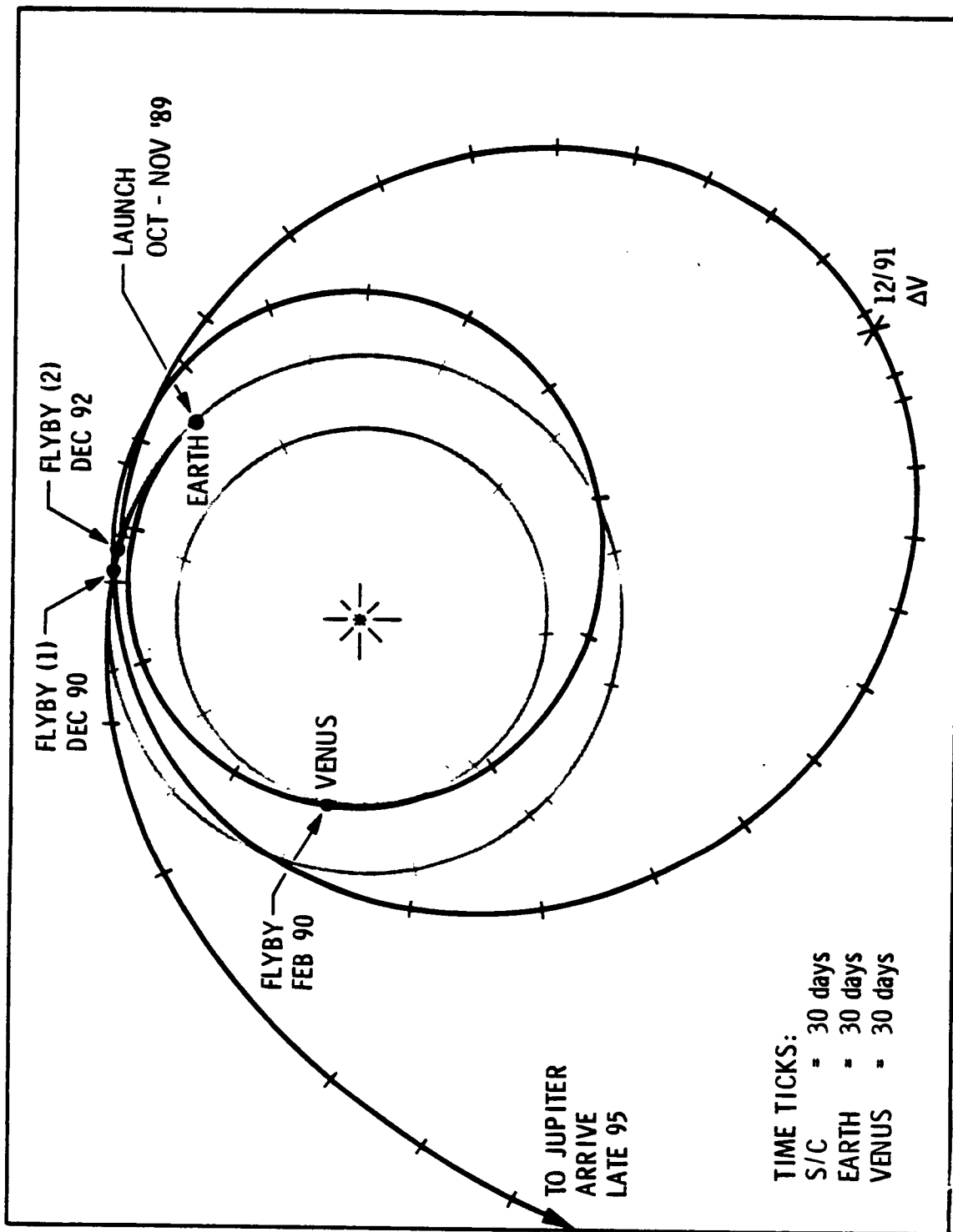


FIGURE 2-1. GALILEO SPACECRAFT TRAJECTORY USING NOVEMBER 1989 VEEGA EXAMPLE

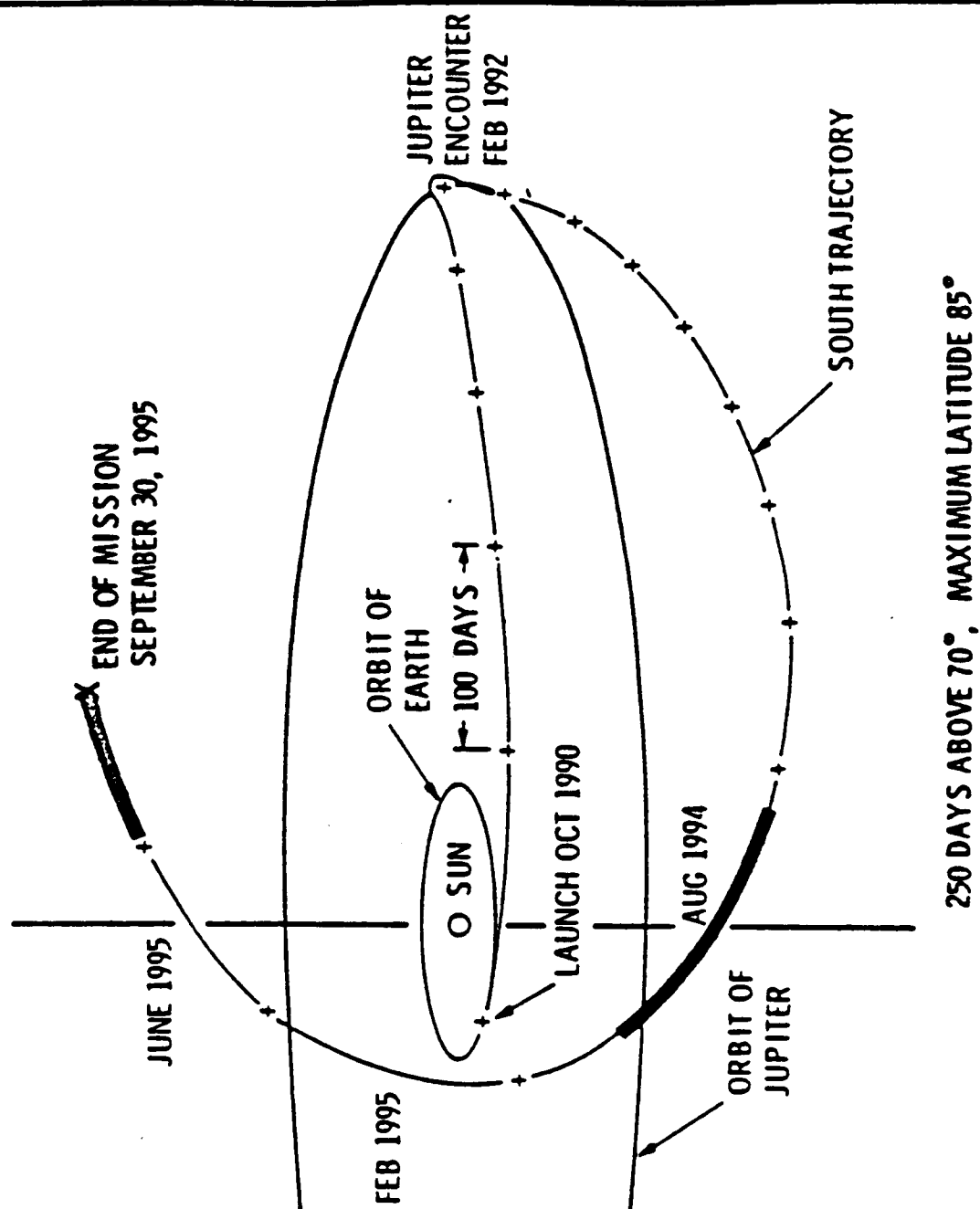


FIGURE 2-2. ULYSSES SPACECRAFT TRAJECTORY AND MISSION PROFILE

2.2.3 Mission Phases and Launch Operations

2.2.3.1 Mission Phases

There are several identifiable phases for the Galileo and Ulysses missions relative to the STS/IUS launch vehicle configuration. All launch vehicles and both missions have the following launch phases:

- Pre-launch - starts a few days prior to launch with the installation of the RTGs on the spacecraft at the launch pad. Following RTG installation, the liquid propellants for the launch vehicles are loaded. This loading of the low-temperature propellants (i.e., liquid hydrogen and liquid oxygen) occurs a few hours before launch.
- Launch-to-Earth-Orbit - starts with ignition of the launch vehicle solid rocket boosters (SRBs) and lift-off from the launch pad. Liquid and solid propellant stages are used by all launch vehicle alternatives to boost the payload into Earth orbit.
- Earth-Orbit - starts with cut-off of the launch vehicle liquid propellant stages at the time that the launch vehicle obtains Earth-orbit velocity. The launch vehicle then coasts for a period of several hours. This coasting period continues until the launch vehicle is properly prepared and positioned for the next phase.
- Earth-Orbit Escape - starts with ignition of the IUS upper stage. This phase ends with the spacecraft both separated from the upper stage and delivered to its deep space trajectory.

For the STS/IUS, a Launch-Abort-Landing phase also must be considered. This phase only would be relevant if an STS/IUS or spacecraft problem occurred that caused the Orbiter and payload to return to Earth before deploying the spacecraft into orbit.

Finally, the Galileo mission also has an Earth-Return-Flyby phase because none of the launch vehicle alternatives has sufficient capability to launch the spacecraft on a direct trajectory to Jupiter. Galileo makes flybys of Earth and Venus to gain sufficient velocity from the gravitational fields of the planets to proceed to Jupiter. For the mission, two Earth-return flybys are used (see Figure 2-1).

2.2.3.2 Mission Safety After Launch

The mission safety actions subject to human intervention after launch that are relevant to this EIS for all alternatives and both missions are: range safety, abort landings, cancellation of spacecraft deployment, and Earth reentry.

Range Safety

The Eastern Space and Missile Center at Patrick Air Force Base is responsible for range safety (i.e., the protection of life and property through the ability to monitor closely launch vehicle performance and destroy the launch vehicle to prevent damage or accident from ground impact of the intact launch vehicle) during NASA launches at the Kennedy Space Center (KSC). To satisfy range safety requirements, all launch vehicles have a range safety system that permits immediate detection of any deviation from the nominal launch trajectory. If it is determined during launch that the launch vehicle constitutes a hazard to life or property, the Range Safety Officer has the responsibility to destroy the launch vehicle.

Abort Landings and Cancellation of Spacecraft Deployment

Pre-defined launch-abort sequences will be activated during the Launch-to-Earth-Orbit phase if the STS flight crew or the on board computers sense malfunctions that would prevent the Orbiter from safely reaching Earth orbit. Similarly, once in the Earth-Orbit phase, spacecraft deployment will be cancelled and the spacecraft will be returned to Earth according to pre-defined mission operation rules if NASA determines that a satisfactory deployment and delivery of this spacecraft to its deep space trajectory is not feasible. Other failure modes may be identified that may involve leaving the spacecraft in low Earth orbit. However, in any event, the RTG modules are designed to survive reentry conditions associated with this phase of the mission.

Earth Reentry

Earth reentry could occur from Earth orbit, for instance due to an upper stage malfunction, or, in the case of Galileo, due to spacecraft malfunction or navigation error during a VEEGA flyby. The environmental implications of an Earth reentry are being investigated as part of the detailed safety and environmental data being developed. As part of the VEEGA mission design, the Galileo project is conducting an Earth Avoidance analysis. Section 4 of this EIS presents the results of that analysis.

2.2.4 Launch Opportunity Considerations

Both the Galileo and Ulysses missions can be launched only during specific periods, or launch windows, depending on the positions of the planets and the capabilities of available launch vehicles. Due to programmatic constraints associated with resumption of Shuttle operations, the first opportunity for the launch of Galileo occurs during October 1989, and for Ulysses occurs during October 1990. The next feasible launch opportunities occur in May/June 1991 for Galileo and October 1990 and November 1991 for Ulysses.

When a mission delay causes a launch opportunity to be missed, spacecraft trajectories and mission operations must be redesigned and generally mission budgets must be augmented. The redesign of mission operations requires new plans for communications, spacecraft tracking, and mission operation facilities support. These new plans affect not only the

delayed missions, but also other missions that depend on the resources of these facilities. Because of the specialized nature of space exploration missions such as Galileo and Ulysses, trained personnel and the use of supporting facilities must be retained when missions are delayed between launch opportunities.

Furthermore, available spacecraft power must be reconsidered when RTGs are required for a mission. RTG power levels decline with time. Therefore, missed launch opportunities may require expensive refueling of existing spacecraft RTGs or may require mission planners to restrict mission objectives.

2.2.5 Spacecraft Descriptions

2.2.5.1 Galileo Spacecraft

The Galileo spacecraft consists of an orbiter and an atmospheric entry probe and weighs 6,000 pounds (see Figures 2-3 and 2-4). The spacecraft is spin-stabilized, but incorporates a despun section for certain scientific equipment. The part of the spacecraft that is de-spun will provide a steady platform for remote-sensing instruments, which must be precisely pointed. The other part of the spacecraft will spin at three revolutions per minute to allow its instruments to "sweep" the sky continuously to make their measurements. The spinning part of the spacecraft contains communication antennas, the spacecraft propulsion subsystem, the RTGs, most of the electronics and communications equipment, and various science instruments.

The portions of the spacecraft that are relevant to the assessment of potential environmental impacts are the power, temperature control, and propulsion subsystems. The particular elements of these subsystems that are of interest are the two RTGs in the power subsystem, the RHUs in the temperature control subsystem, and the propellants in the attitude control and propulsion subsystem.

2.2.5.2 Ulysses Spacecraft

The Ulysses spacecraft weighs 805 pounds and is illustrated in Figure 2-5. The spacecraft is spin-stabilized with an antenna on top, one RTG, a boom used for selected scientific experiments, and a main body that contains the remainder of the science experiments and the spacecraft subsystems.

The portions of the spacecraft that are relevant to assessing potential environmental impacts are the power and propulsion subsystems. The particular elements of these subsystems that are of interest are RTG use in the power subsystem and the propellants in the attitude control and propulsion subsystem.

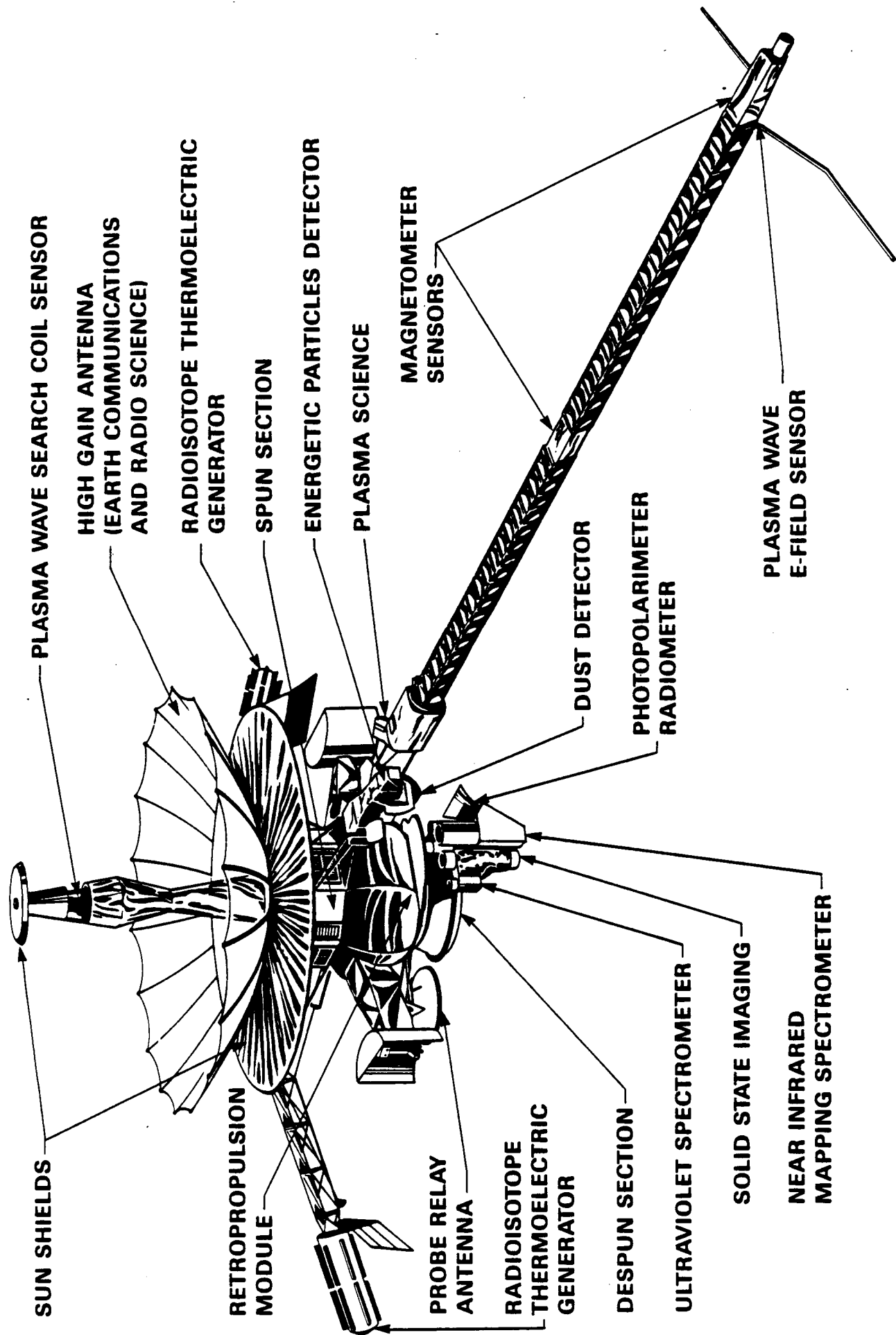


FIGURE 2-3. DIAGRAM OF GALILEO ORBITER

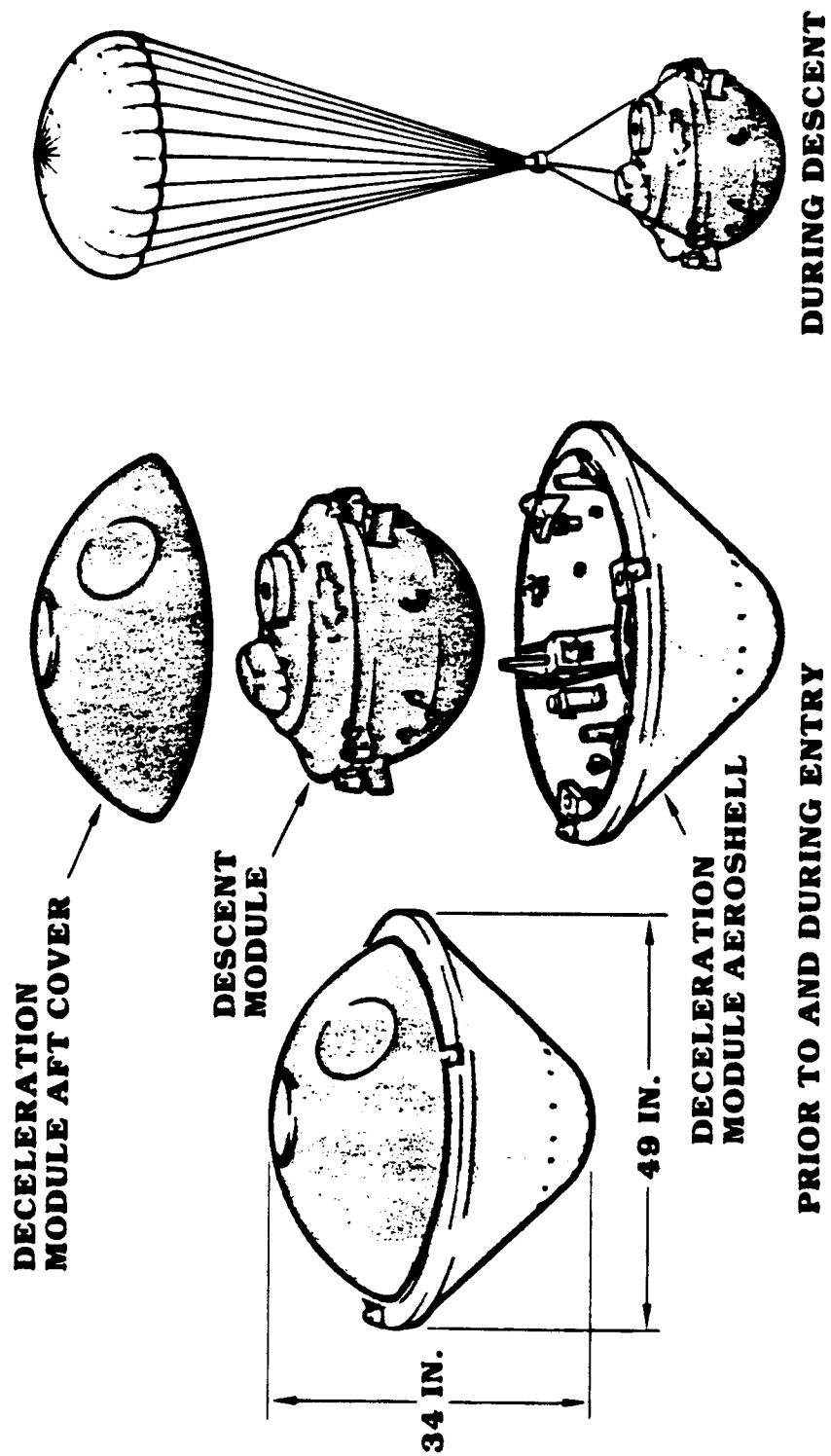


FIGURE 2-4. DIAGRAM OF GALILEO PROBE

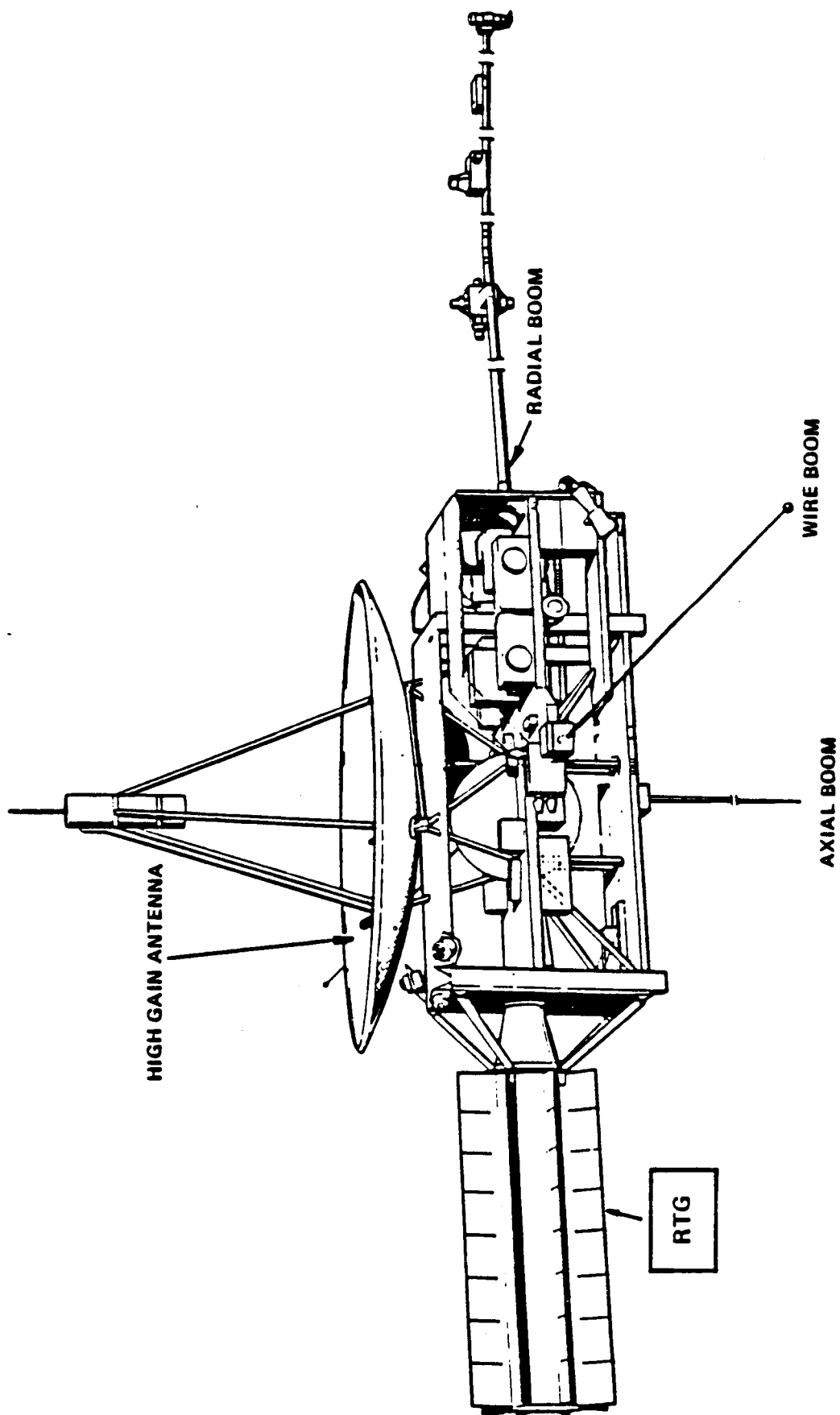


FIGURE 2-5. DIAGRAM OF SPACECRAFT CONFIGURATION FOR ULYSSES

2.2.6 Power Sources

2.2.6.1 Consideration of Alternative Power Sources

The power requirements for the Galileo and Ulysses spacecraft include the following performance criteria:

- (1) Safe passage through the asteroid belt
- (2) Prolonged operation in the intense radiation field of Jupiter
- (3) Sufficient power to operate at Jupiter's distance from the Sun
- (4) Sufficient power to function for at least 43 months after the Jupiter encounter
- (5) Low weight-to-power ratio
- (6) Maximum reliability.

RTGs are the only available power sources that meet all six requirements. Alternatives to the RTGs as a source of electrical power for the spacecraft were considered. These alternatives included solar cells, fuel cells, batteries, nuclear reactors, and radioisotope dynamic generators. Solar cells cannot meet requirements (1) through (4) because solar cells are susceptible to impacts with interplanetary dust particles, their performance will degrade in the intense radiation field of Jupiter, and the intensity of the Sun near Jupiter is about 25 times less than that at Earth. Fuel cells and batteries cannot meet requirements (4) and (5) because of their lower power densities relative to weight, thus requiring more launch energy than is available. Other nuclear power sources such as nuclear reactors and radioisotope-driven dynamic generators are not available.

2.2.6.2 Radioisotope Thermoelectric Generators (RTGs)

Electrical power for the Galileo and Ulysses spacecraft will be obtained from RTGs. Each RTG (see Figure 2-6) is designed to provide a minimum of 285 Watts at the beginning of each mission. RTGs have been used on 22 previous space missions. These applications have included some of NASA's most impressive successes, including Voyager, Pioneer, Viking, and all but the first of the manned Apollo landings on the Moon. Each RTG has a heat source and a thermoelectric converter that converts heat into electricity. The locations of the RTGs on the Galileo and Ulysses spacecraft were provided in Figures 2-3 and 2-5, respectively.

The U.S. Department of Energy (DOE) safety philosophy for the design of the RTG requires containment or immobilization of the plutonium fuel to the maximum extent possible during all mission phases, including ground handling, launch, and unplanned events such as reentry, impact, and post-impact situations.

The RTG consists of a heat source and a thermoelectric converter. The RTG heat source consists of a stacked column of 18 individual modules. Each general purpose heat source (GPHS) module contains one graphite block, called an aeroshell that encases two graphite cylinders called graphite impact shells (see Figure 2-7). Each cylinder contains two pellets of plutonium dioxide encased in iridium/tungsten alloy metal. The graphite blocks provide protection against atmospheric heating and subsequent release of the plutonium dioxide in the event that the modules are released in an

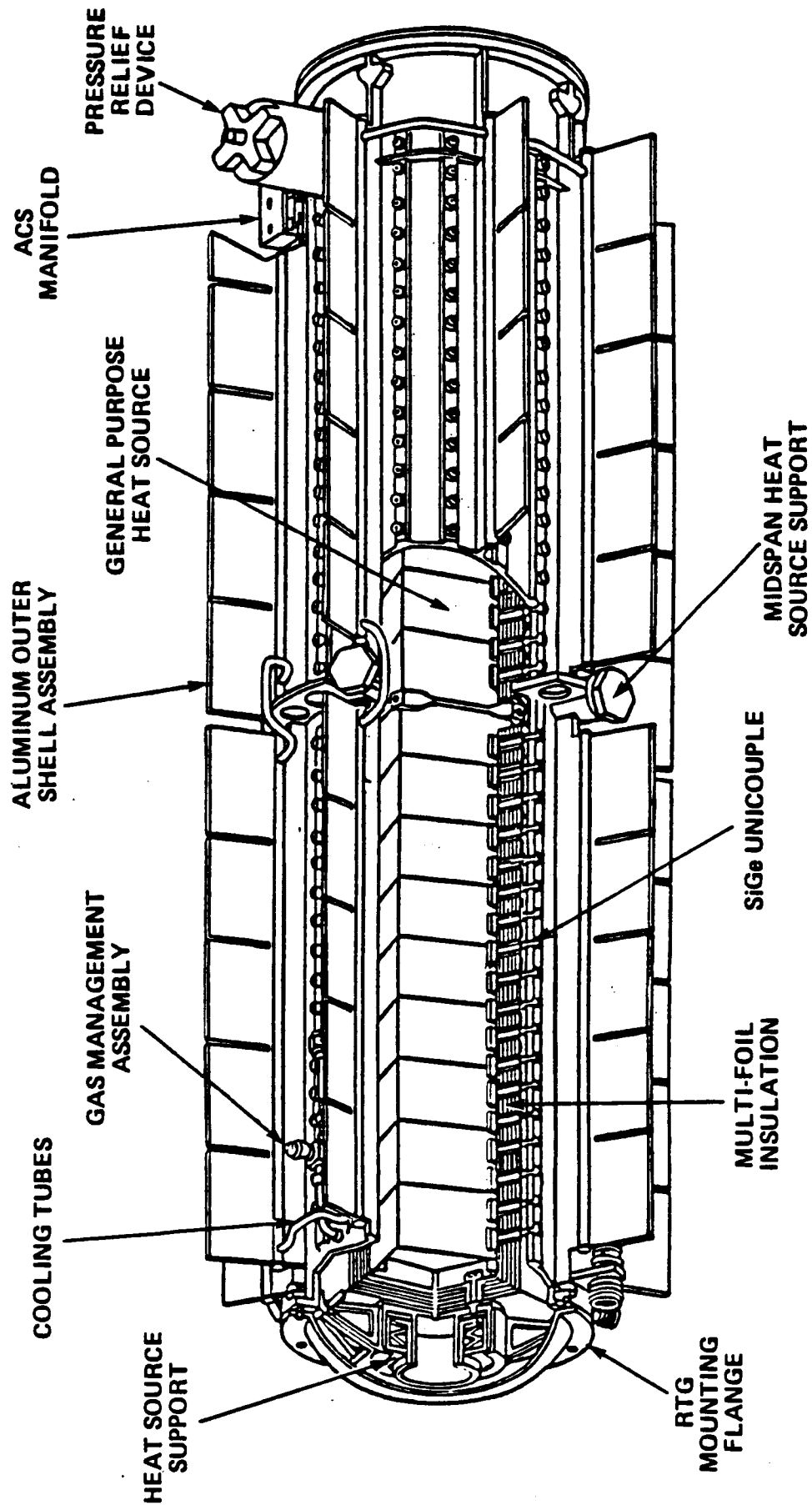


FIGURE 2-6. DIAGRAM OF RTG ASSEMBLY

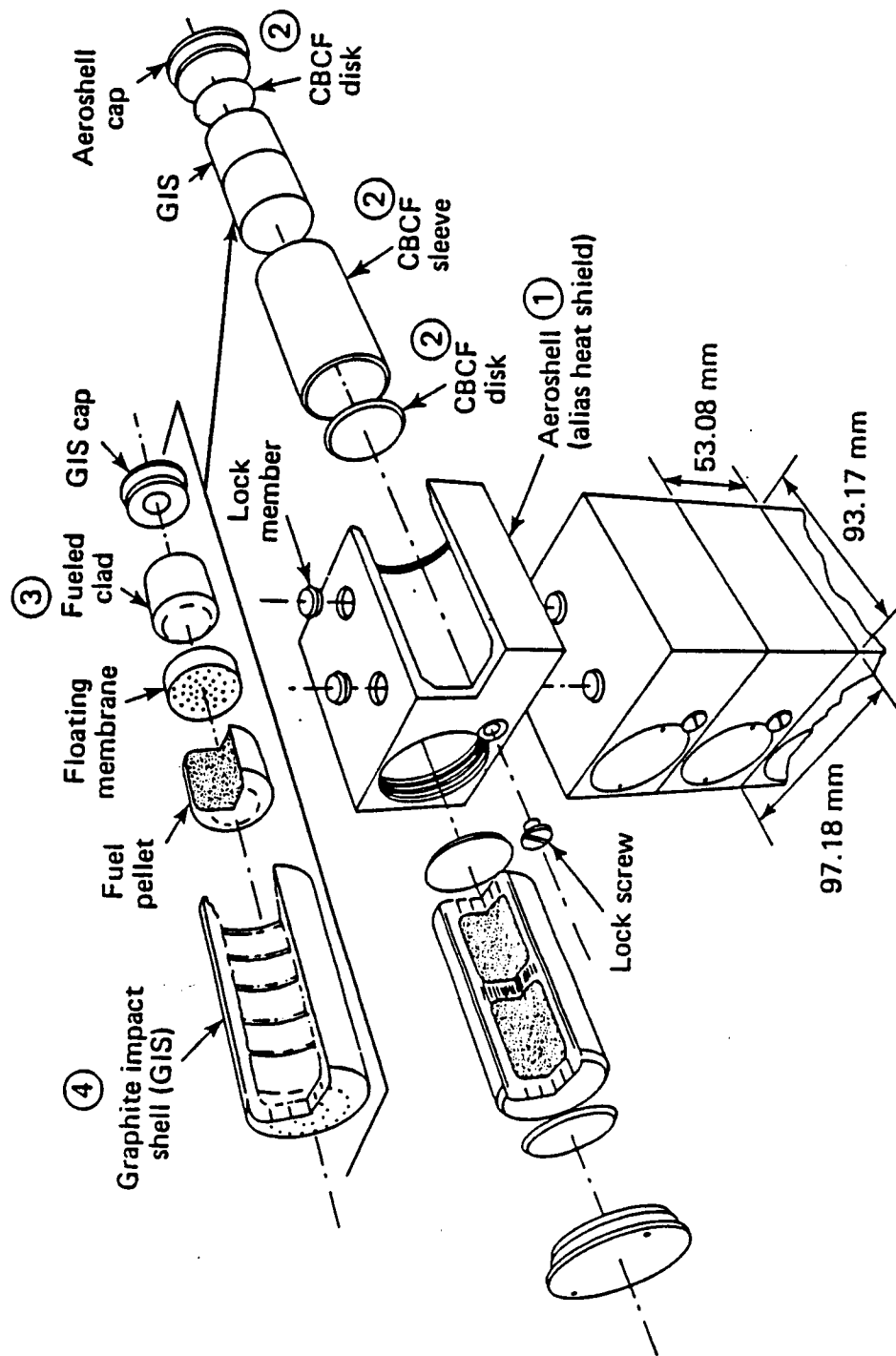


FIGURE 2-7. DIAGRAM OF GENERAL PURPOSE HEAT SOURCE RTG MODULE

accident and fall back to Earth. The graphite cylinders provide protection from ground or debris impacts in the event of an accident. The iridium/tungsten metal contains the fuel and provides an additional layer of protection.

The plutonium dioxide generates heat by the natural radioactive decay largely of the Pu-238 isotope. Table 2-1 provides a breakdown and isotopic composition of the 9.540 kgs of plutonium used to manufacture an RTG (see Ref. 12).

TABLE 2-1. ISOTOPIC COMPOSITION OF PLUTONIUM USED TO MANUFACTURE AN RTG*

Plutonium Isotope	Weight Percent	Half-Life (Years)	Radioactivity (Curies/gram of plutonium)	Total Curies (11/89)
236	<10 ⁻⁶	2.85	532	<1
238	83.880	87.7	17.1	130,050
239	13.490	24,100	0.0621	80.2
240	1.900	6,560	0.227	41.3
241	0.379	14.4	103.2	2,650
242	0.124	376,000	0.00393	<1
Other TRU isotopes	<u>0.228</u>	---	---	<u>3.3</u>
TOTALS	100.00	---	---	132,825

*Based on values from Table A-1, Ref.32.

Until the RTGs are transported to the KSC, they will be stored at a DOE facility. A few days before launch, the RTGs will be installed on the spacecraft.

2.2.7 Radioisotope Heater Units (RHUs)

The Galileo spacecraft will use approximately 130 RHUs to maintain portions of the orbiter/atmospheric entry probe temperature within acceptable limits, to minimize the use of electrical power for thermal control, and to reduce electromagnetic interference. Each RHU provides about 1 Watt of heat derived from the radioactive decay of 31.5 Curies of plutonium-238. The plutonium (in the form of a plutonium dioxide pellet) for each RHU is contained within a platinum-rhodium alloy capsule. Similar to the RTGs, each RHU is encased in a graphite insulator surrounded by a graphite block to provide protection from atmospheric heating and ground or debris impact in the event of an accident (see Figure 2-8). The RHUs are

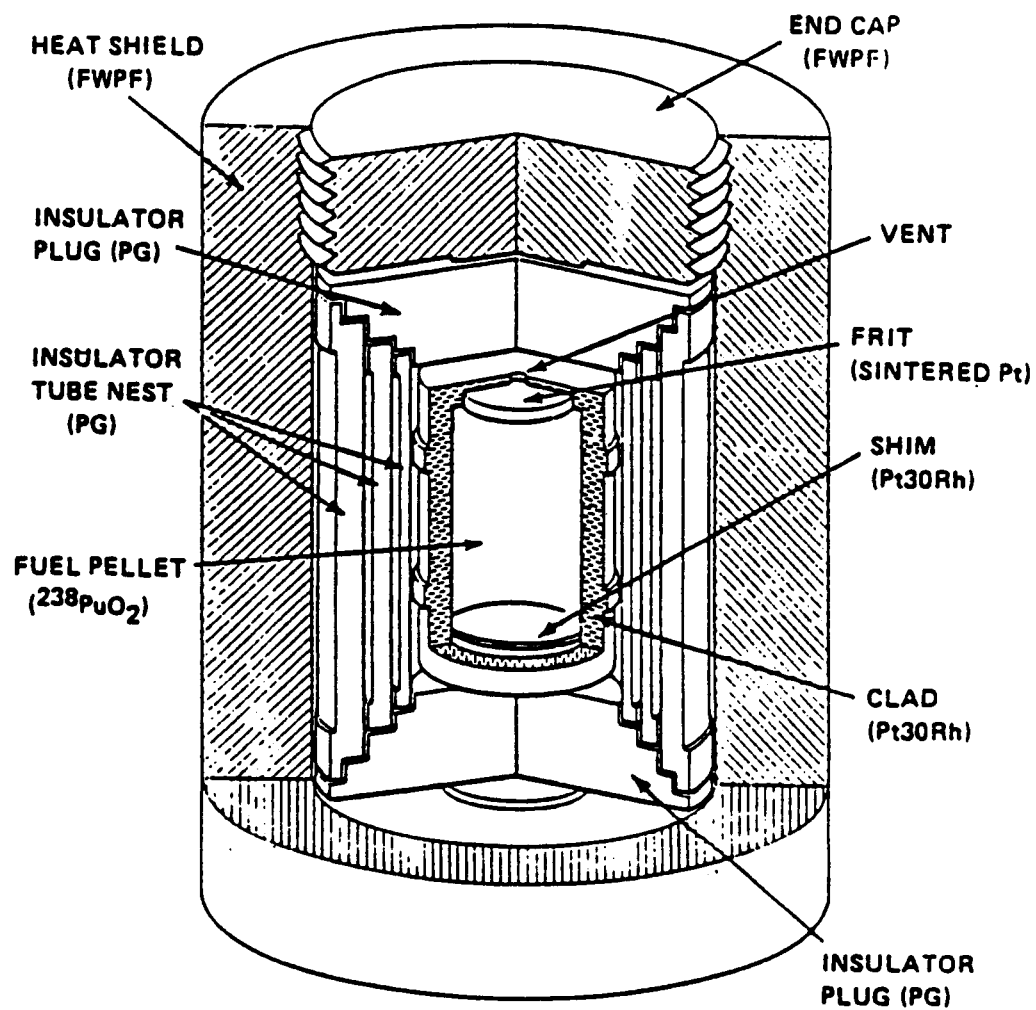


FIGURE 2-8. DIAGRAM OF RHU MODULE

designed to be lightweight units capable of containing the plutonium dioxide fuel in all credible situations of both normal operations and accidents. The locations of RHUs on the Galileo spacecraft are shown in Figure 2-9.

The only alternative to the Galileo spacecraft RHUs would be the addition of another RTG, which would result in an unacceptable weight increase for the spacecraft.

2.2.8 Spacecraft Propulsion Subsystem

The Galileo spacecraft uses monomethyl hydrazine fuel and nitrogen tetroxide oxidizer for its propulsion subsystem. This propellant combination is hypergolic (i.e., the propellants ignite spontaneously upon contact with each other). The Ulysses spacecraft propulsion subsystem uses hydrazine, which spontaneously ignites by catalytic decomposition within the propulsion subsystem thrust chambers. These combinations are the most efficient, space-storable (i.e., can be stored without any special temperature control equipment) propellants available for the missions, and the use of any other space-storable propellants would result in unacceptable weight increases for the spacecraft. The propellant tanks of both spacecraft are loaded at the KSC. The Galileo spacecraft carries 807 pounds of monomethyl hydrazine and 1,293.6 pounds of nitrogen tetroxide. The Ulysses spacecraft carries 74 pounds of hydrazine. NASA has prescribed specifications concerning the storage and handling of these propellants (Ref. 3).

2.2.9 Launch Vehicle Descriptions

NASA's launch vehicle for the launch opportunity available in October 1989 for Galileo and October 1990 for Ulysses is the STS with an IUS (supplemented by a PAM-S third stage for the Ulysses mission). The STS/IUS launch configuration consists of the STS Shuttle booster with an IUS that is carried to Earth orbit in the Shuttle bay. Figure 2-10 illustrates the configuration of the spacecraft in the Shuttle bay for launch.

The STS consists of a piloted reusable vehicle (the Orbiter) mounted on a non-reusable External Tank (ET) containing liquid hydrogen and oxygen propellants and two recoverable and reusable Solid Rocket Boosters (SRBs). The Orbiter has three main rocket engines and a cargo bay 60 feet long by 15 feet in diameter (Ref. 28).

At launch, both SRBs and the Orbiter's rocket engines burn simultaneously. When the Shuttle vehicle attains an altitude of approximately 27 miles, the SRBs are jettisoned and subsequently recovered from the ocean. The ET is jettisoned before the Orbiter goes into Earth orbit. The Orbiter's Orbital Maneuvering System (OMS) is then used to propel the Orbiter into the desired Earth orbit. The OMS also is used to take the Orbiter out of orbit. The Orbiter is piloted back to Earth for an unpowered landing. A detailed description of the STS Shuttle has been provided in the Shuttle Data Book (Ref. 28).

The IUS extends the Space Shuttle's reach beyond the Shuttle's highest achievable altitude. After deployment from the Shuttle, the IUS can propel payloads into higher Earth orbits or to Earth-escape velocities, the latter

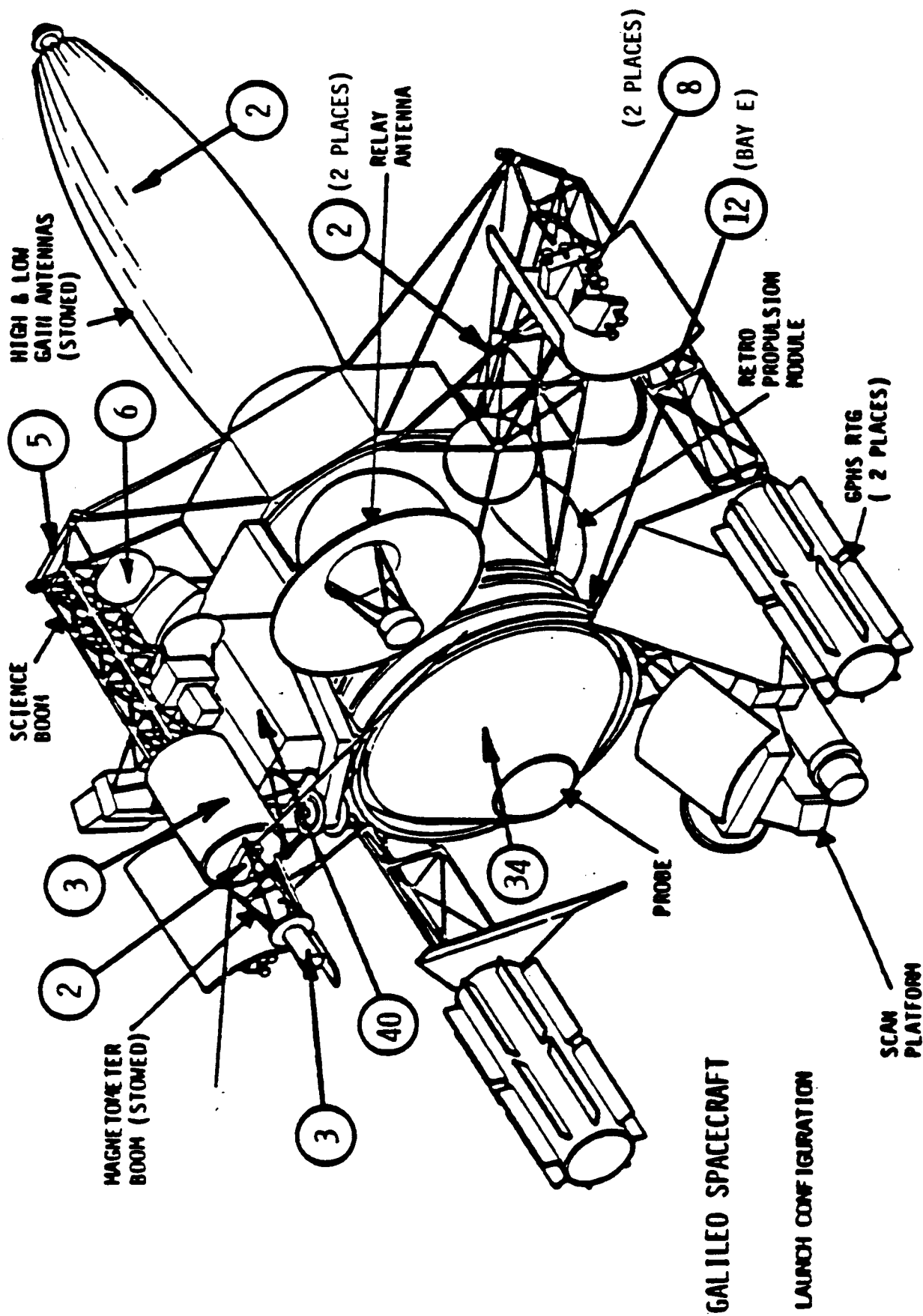
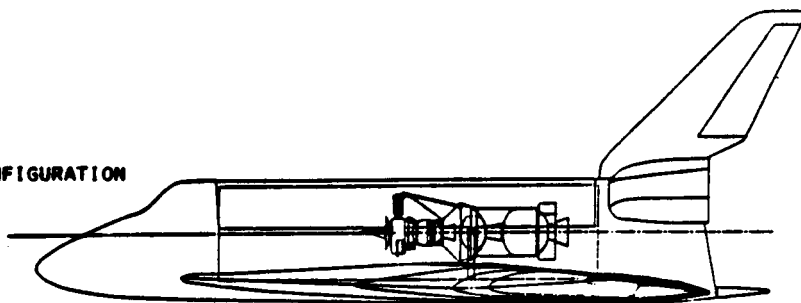
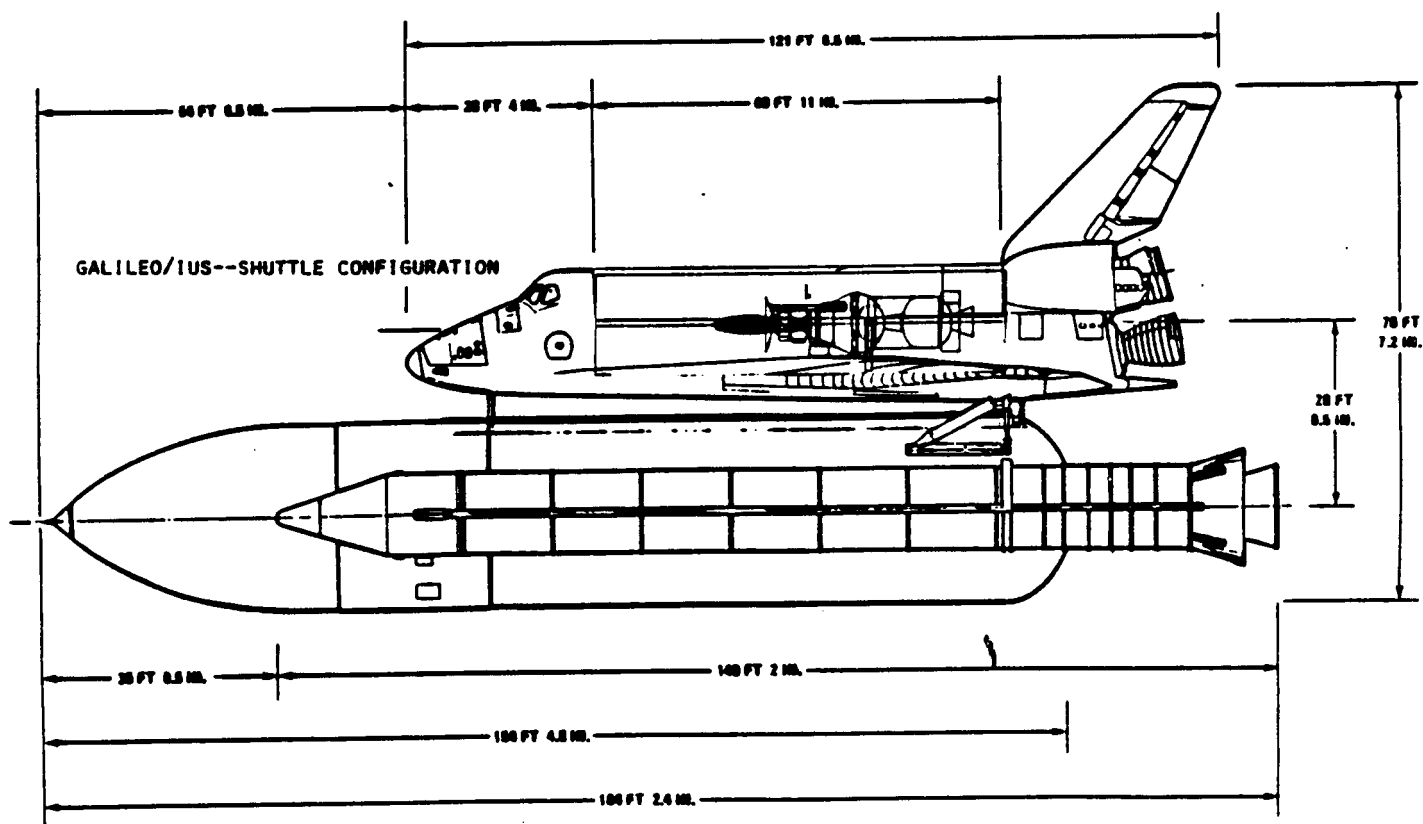


FIGURE 2-9. DIAGRAM OF LOCATIONS OF RHUS ON GALILEO SPACECRAFT

ULYSSES/IUS--SHUTTLE CONFIGURATION



GALILEO/IUS--SHUTTLE CONFIGURATION



2-20

of which is needed for deep space missions. The version of the IUS proposed for use with the Galileo and Ulysses missions is a two-stage solid rocket (Ref. 4). Figures 2-11 and 2-12 illustrate the configuration of the spacecraft assembled with the IUS for Galileo and Ulysses, respectively.

The PAM-S is a solid rocket booster that would be used as an additional stage separate from the two-stage IUS. The PAM-S is fired after the IUS burn has been completed. The Ulysses mission requires the PAM-S to achieve the additional velocity needed to deliver the spacecraft onto its deep space trajectory.

2.3 DESCRIPTION OF THE ALTERNATIVE TO DELAY THE PROGRAM, INCLUDING STOPPING MODIFICATIONS TO THE SPACECRAFT, UNTIL THE SAFETY ANALYSIS REPORT AND THE ADDITIONAL NEPA RELATED DOCUMENTATION ARE COMPLETE, PRECLUDING A LAUNCH OF GALILEO IN 1989, BUT STILL ALLOWING A ULYSSES LAUNCH IN 1990

This alternative would involve the suspension of the modification to the spacecraft until the SARs and additional NEPA related documentation are completed. In the event that this alternative is selected, the Galileo spacecraft could not be ready for launch in October 1989. The Ulysses spacecraft could be launched in October 1990 if programmatic activities and preparation costs currently shared with Galileo related to RTG safety, RTG cooling requirements, and IUS integration were picked up by Ulysses through a budget supplement to cover Galileo's portion of the shared costs. Either spacecraft could be launched in 1991 on the STS.

The delay alternative allows several potential Galileo launch vehicle configurations, including: 1) the STS/IUS currently planned, and 2) the use of an expendable launch vehicle configuration such as the Titan IV/IUS. The expendable launch vehicle (i.e., the Titan IV) is still in development and may not be available for the 1991 launch opportunities, which would result in an additional delay of at least 18 months for Galileo and 13 months for Ulysses until the next launch opportunity beyond 1991.

2.3.1 Alternative Launch Configurations for Delayed Launches

This section discusses alternative launch vehicle configurations available for delayed launches. Table 2-2 displays these configurations relative to the 1989 configuration. The Titan IV configurations assume that the Titan IV development program, as currently planned, will result in an operational Titan IV/IUS by 1991 or Titan IV/Centaur by 1993 at the earliest. For launches beyond 1993, the Titan IV/Centaur may be available. However, the Titan IV/Centaur will not be available for a launch in the 1989-1991 timeframe anticipated for the Galileo or Ulysses missions and therefore will not be considered further in this EIS.

2.3.1.1 Delayed STS/IUS Configuration

The STS/IUS launch configuration for a launch in 1989 or beyond would essentially be the same as the STS/IUS launch configuration discussed in Section 2.2. Other than the possible addition of batteries to the Galileo spacecraft to provide peak power (because of degradation of RTG power

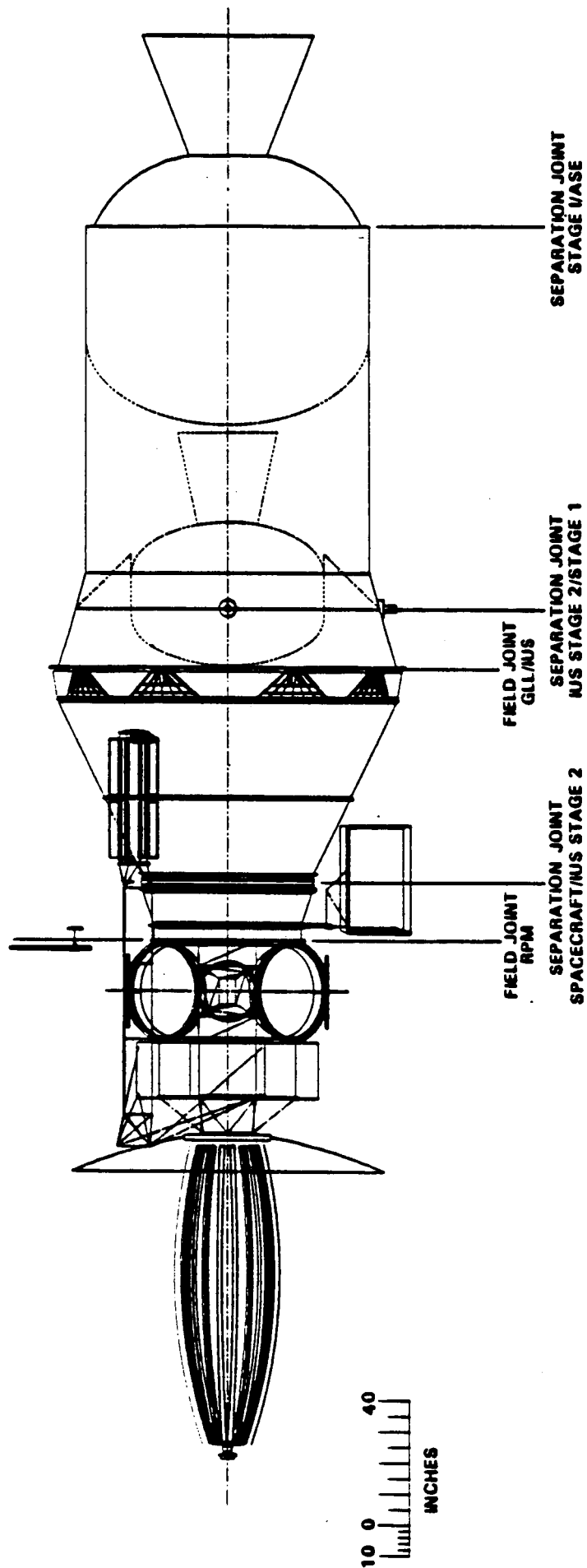


FIGURE 2-11. CONFIGURATION OF GALILEO SPACECRAFT ASSEMBLED WITH IUS.

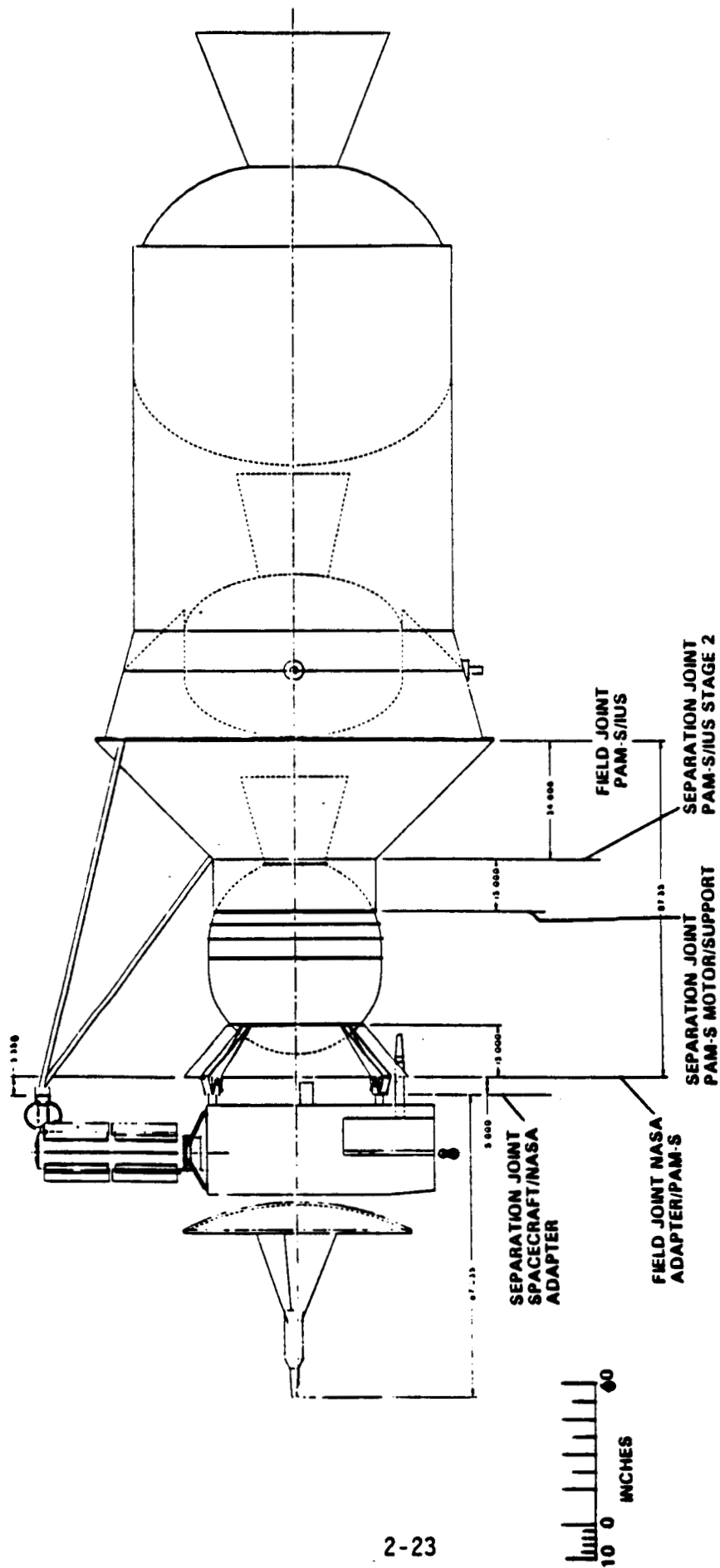


FIGURE 2-12. CONFIGURATION OF ULYSSES SPACECRAFT ASSEMBLED WITH IUS/PAM-S.

TABLE 2-2. LAUNCH VEHICLE CONFIGURATIONS

Launch Configuration	Flight Segment				
	Liftoff	Liquid Rocket Burn	Earth-Orbit Operations	Interplanetary Trajectory Injection	Earth-Flyby
<u>GALILEO</u>					
<u>1989 Launch STS/IUS</u>	SRBs and Main Shuttle Engines	Main Shuttle Engines	Yes	IUS	Yes
<u>1991 Launch STS/IUS</u>	SRBs and Main Shuttle Engines	Main Shuttle Engines	Yes	IUS	Yes
<u>Titan IV/IUS</u>	SRBs	Main Engine (2 stages)	Optional	IUS	Yes
<u>ULYSSES</u>					
<u>1990 Launch STS/IUS/PAM-S</u>	SRBs and Main Shuttle Engines	Main Shuttle Engines	Yes	IUS/PAM-S	No
<u>1991 Launch STS/IUS/PAM-S</u>	SRBs and Main Shuttle Engines	Main Shuttle Engines	Yes	IUS/PAM-S	No
<u>Titan IV/IUS/PAM-S</u>	SRBs	Main Engine (2 stages)	Optional	IUS/PAM-S	No

levels), there are no known substantial changes that would be required for a launch after 1989.

2.3.1.2 Expendable Launch Vehicle Configurations

For launches in the early 1990's and beyond, it is expected that two launch vehicle configurations using the Titan IV rocket coupled with either a Centaur or IUS could be available to launch the Galileo and Ulysses spacecraft.

The Titan IV has been designed to accept the STS payloads. The Titan IV consists of a two-stage liquid-propellant core vehicle with two attached SRBs. Figure 2-13 provides a comparison of the Titan IV configuration to the Titan IIIE Centaur configuration.¹ The SRBs provide the initial thrust at lift-off from the launch pad. After the SRBs complete their burn, the first stage of the liquid-propellant core is ignited. Two minutes after ignition of this stage, the payload fairing is jettisoned. Following the shutdown of the first stage, the second stage is ignited and burns to completion. The Titan IV/IUS is currently being developed by the DOD and will not be available to NASA (according to current plans) until 1991.

2.3.2 Spacecraft and Mission Changes Caused by Delayed Launches and Alternative Configurations

There are no spacecraft or mission changes required as a result of delays to 1991. However, any launches beyond 1991 would necessitate certain changes in the spacecraft and mission from those described in Section 2.2. The principal changes now expected would be mission design and trajectory changes and the possible refueling of the RTGs (for missions beyond 1991) to compensate for the reduction in RTG power output due to radioisotope fuel decay.

A 1991 launch of Galileo on board the STS/IUS or Titan IV/IUS would require the VEEGA trajectory. Operational procedures have been developed to minimize the chance of an inadvertent Earth reentry occurring during the Earth-return-flyby.

2.4 DESCRIPTION OF THE ALTERNATIVE TO CONTINUE WITH EITHER THE GALILEO OR ULYSSES MISSION AND CANCEL THE OTHER

The alternative to continue with either the Galileo or Ulysses mission, while cancelling the other mission, would result in the termination of the further commitment of resources to one of the two missions and the loss of scientific returns from the cancelled mission. The mission that is continued could be launched under either of the launch scenarios discussed previously. The environmental considerations for this alternative are the same as those previously discussed under the proposed action or the delay alternative.

¹Whereas the Titan IIIE was used for the Voyager missions, it is not large enough to satisfy the requirements of the Galileo and Ulysses missions.

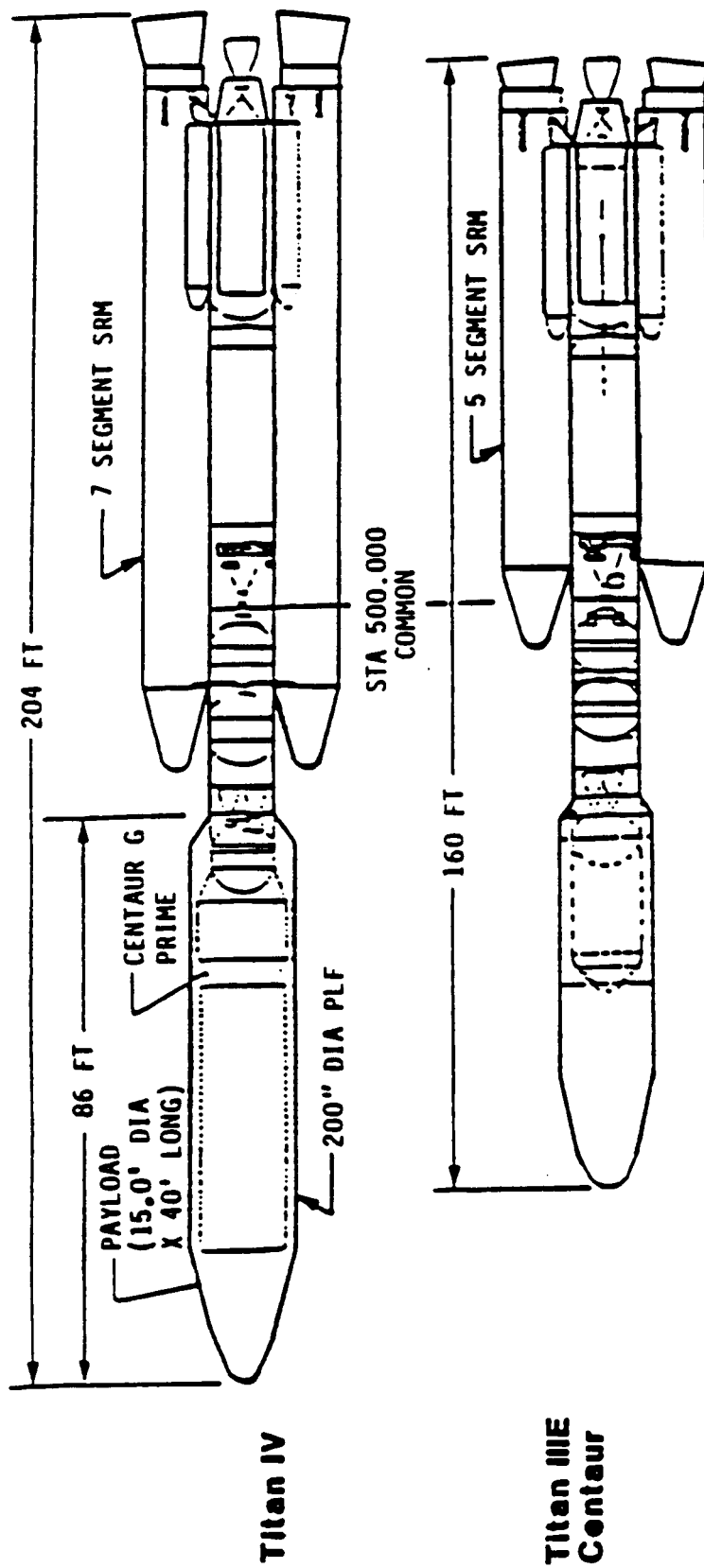


FIGURE 2-13. DIAGRAM COMPARING TITAN IV CONFIGURATION TO TITAN III E

2.5 DESCRIPTION OF THE NO-ACTION ALTERNATIVE

The no-action alternative would result in the termination of the further commitment of resources to both missions. If NASA did not proceed with the Galileo and Ulysses missions, the goals of the NASA Solar System Exploration Program relating to both missions would not be attained.

2.6 SUMMARY COMPARISON OF ALTERNATIVES

No adverse environmental consequences have been identified for any of the alternatives evaluated above. There are, however, significant adverse programmatic, economic, and geopolitical consequences associated with all alternatives other than the proposed action. The proposed action to continue with spacecraft modifications in parallel with ongoing safety and environmental analyses, has significant advantages relative to the other three alternatives evaluated. The proposed action would preserve the 1989 launch opportunity for the Galileo Mission and further enhance NASA's ability to launch the Ulysses Mission in 1990, and would not compromise the science returns from either mission. In addition, the proposed alternative retains for NASA the flexibility of launching either or both missions in 1991 using either the STS or the Titan IV launch vehicles.

Delaying spacecraft modifications until the safety and environmental analyses are complete would eliminate the 1989 launch window for Galileo. While the 1990 launch of Ulysses could be preserved, any additional delays in the recertification program could result in loss of the 1990 launch window. In that event, both missions could be launched in 1991. Potential science returns would remain intact for this alternative, and NASA would retain the flexibility to launch Ulysses in 1990 with the STS or both missions in 1991 with either STS or the Titan IV. The potential for delay of the Ulysses Mission until 1991 would, however, have adverse economic and programmatic impacts. Skilled, experienced personnel could be lost from the program. While the skills could be replaced, the loss of the experience base would be a significant adverse impact to NASA's Solar System Exploration Program and its goals.

Cancelling one mission and continuing with the other would result in the loss of science returns from the cancelled mission and a loss of either the \$735 million invested in Galileo or \$135 million invested in Ulysses (through FY 1987). Cancellation of Galileo would also adversely impact the position of the United States as the world leader in the exploration of the outer planets, since there are currently no other approved United States missions to the outer planets. Cancellation of Ulysses would adversely affect the Global Geospace Science initiative involving the United States, ESA and Japan and our perceived reliability as a partner in joint space exploration.

Cancelling both missions would result in the loss of the total \$870 million investment in the two missions, and would adversely impact the Solar System Exploration Program through the almost irreplaceable loss of the experience base represented by the large number of scientists and engineers who would be difficult to retain within the program. The adverse geopolitical consequences associated with the cancellation of the Ulysses

mission would arise from the perceived unreliability of the United States as a partner in joint space exploration.

3. AFFECTED ENVIRONMENT

This section of this Final (Tier 1) Environmental Impact Statement (EIS) describes the project related environments potentially affected by the proposed action. The information presented in this section provides the necessary frame-of-reference for understanding the discussions presented in Section 4 addressing "Environmental Consequences".

3.1 LAUNCH AREA ENVIRONMENT

The following description of the local and regional Kennedy Space Center (KSC) area summarizes information contained in the National Aeronautics and Space Administration's (NASA's) Kennedy Space Center Environmental Resources Document (Ref. 5), NASA's Kennedy Space Center Environmental Impact Statement (Ref. 6), and the U.S. Department of Energy's (DOE's) Kennedy Space Center Demographic and Land Use Study (Ref. 7). These three documents form the "baseline ecology" for considering NASA's proposed action for the Galileo and Ulysses missions. Additional information on all aspects of the local and regional KSC area is available in these three documents.

3.1.1 Local

The KSC is located on the east coast of Florida, 30 miles south of Daytona Beach and 40 miles due east of Orlando, adjacent to the Cape Canaveral Air Force Station (see Figure 3-1). The KSC is part of the Gulf-Atlantic coastal flats and occupies Cape Canaveral and the north end of Merritt Island. The KSC is approximately 35 miles in length and from 5 to 10 miles in width (see Figure 3-2). NASA maintains operational control over approximately 6,507 of the 139,490 acres of the KSC. About 62 percent of the NASA operational area is currently developed as facility sites, roads, lawns, and maintained right-of-ways (Ref. 5).

3.1.1.1 Land Use

The KSC is NASA's primary installation for launch operations and related programs in support of both manned and unmanned space missions. The developed land areas at KSC contain approximately 278 buildings, facilities, and support areas. Developed facilities within the NASA operational area are dominated by the Shuttle Landing Facility, the Industrial Area, and the Vehicle Assembly Building area. These three areas comprise more than 70 percent of the NASA operational area. There are approximately 211 miles of roadway at KSC with 163 miles of paved roads and 48 miles of unpaved roads (Ref. 5).

Normal operations at KSC include: spacecraft assembly and integration; design, development, and operation of ground support equipment; tracking and data acquisition; launch operations for the Shuttle and expendable vehicles; recovery and refurbishment of the Shuttle Solid Rocket Boosters (SRBs); landing operations of the Shuttle; logistical support for flight operations; and design, construction, and operation of launch facilities.

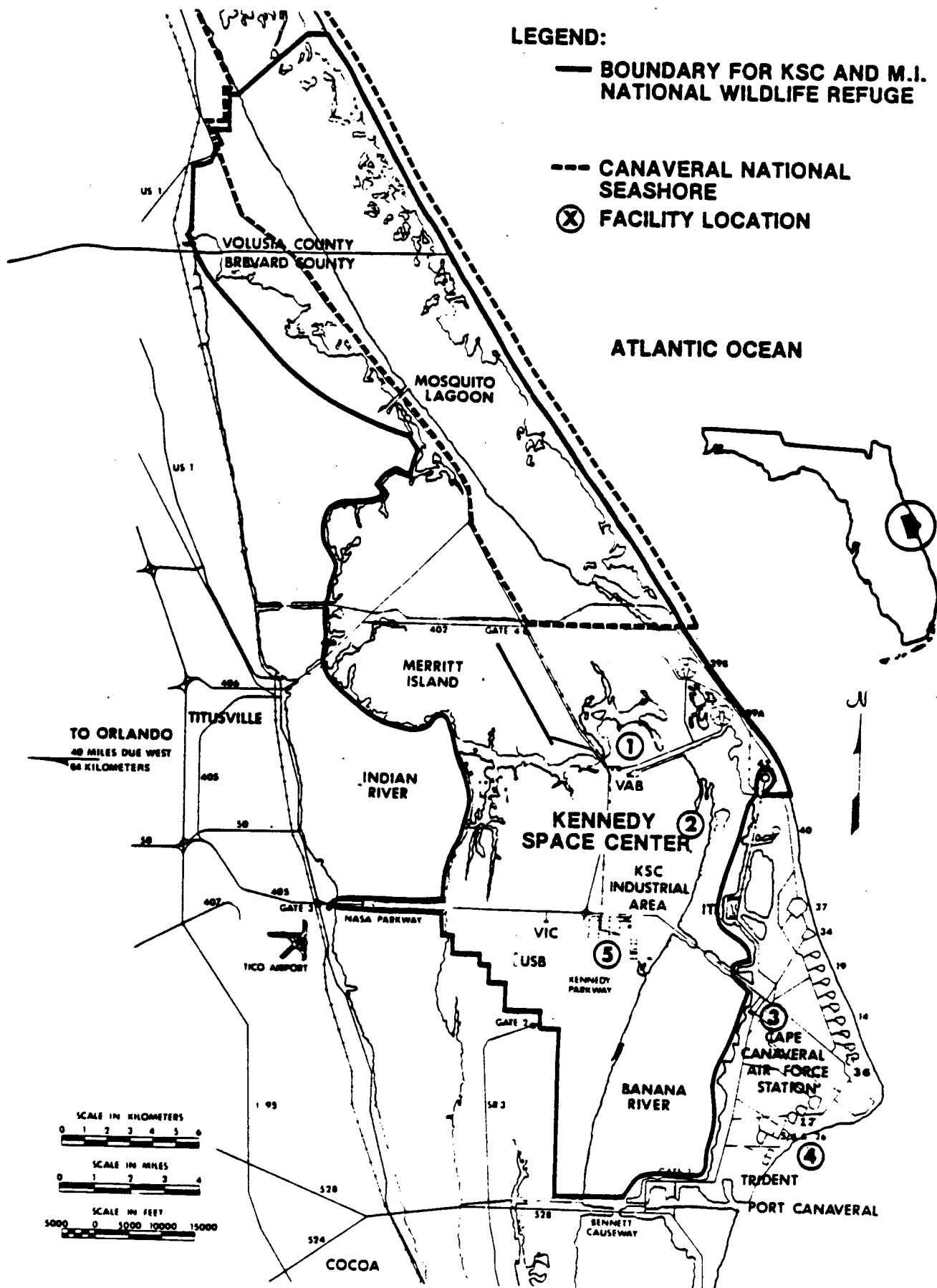


FIGURE 3-1. KENNEDY SPACE CENTER/MERRITT ISLAND AND VICINITY

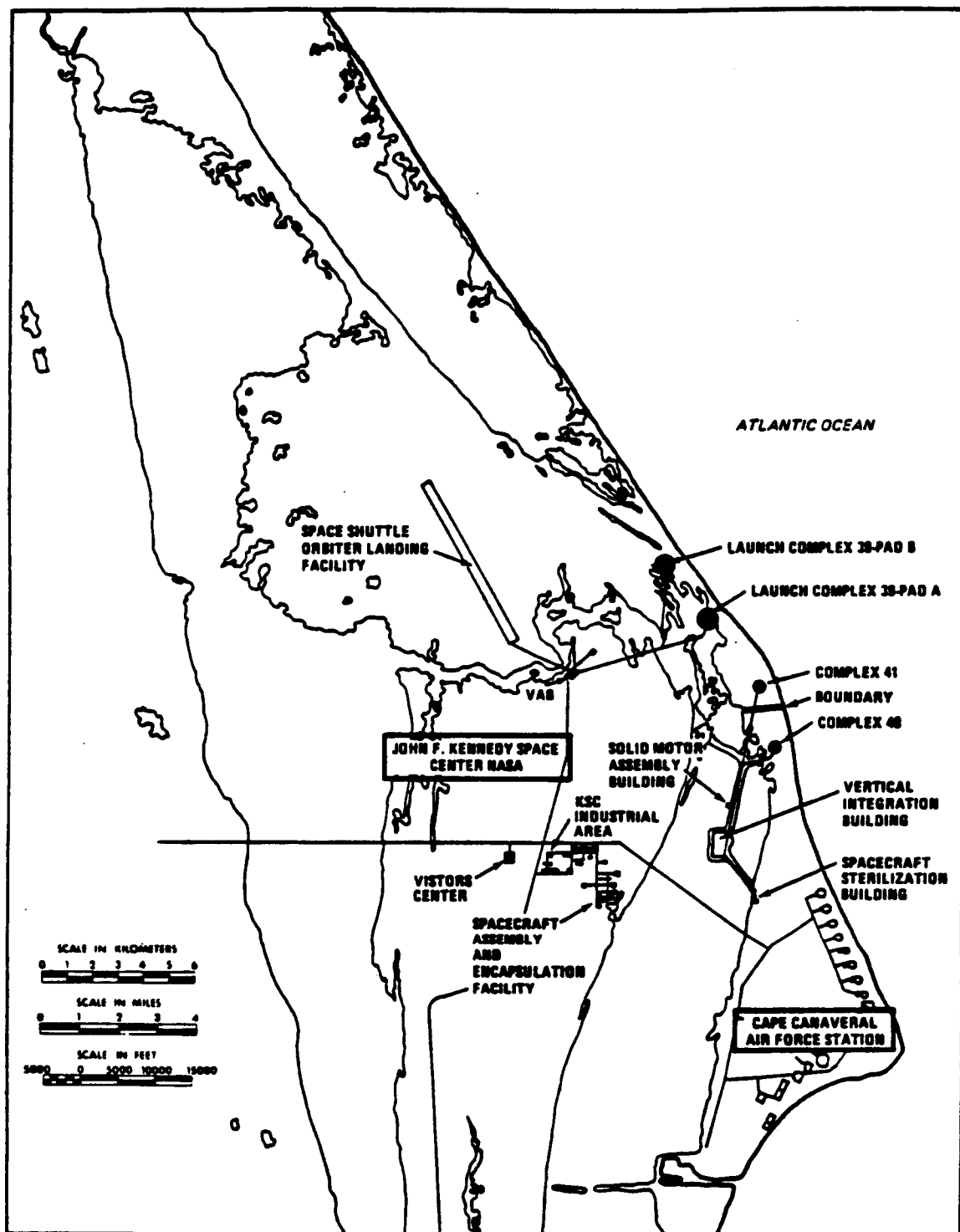


FIGURE 3-2. KENNEDY SPACE CENTER LOCATION MAP

The approximately 95 percent of the KSC land area that is undeveloped consists of wetlands, uplands, water control areas, and mosquito control impoundments. The flora and fauna that inhabit this area have been extensively catalogued, and those that are listed as rare and endangered are constantly monitored. Also, NASA and the U.S. Fish and Wildlife Service have established a wildlife preserve on Merritt Island, within KSC boundaries, for protecting unique and endangered species indigenous to the area. The U.S. Fish and Wildlife Service administers all 75,383 acres of the Merritt Island National Wildlife Refuge and 50,945 acres of the Canaveral National Seashore. The remaining 6,655 acres of the Canaveral National Seashore are administered by the National Park Service (Ref. 5).

The nearby land area of significance to KSC launches is that identified as the estuary of the Banana River, Indian River, and Mosquito Lagoon (Ref. 8). All of the on shore area within 20 kilometers of the launch site is included in the above designated estuary area. Merritt and other barrier islands make up about 60 percent of these 460,000 acres and about 65 percent of this area is either water or nonagricultural land. The remaining area is used for citrus production (about 3 percent), pasture (about 0.3 percent), forest land (about 12 percent), and miscellaneous agriculture (about 19 percent).

3.1.1.2 Climate

The KSC climate is subtropical, with short, mild winters and hot, humid summers. The rainy season (May to October) produces southeast winds and daily thunderstorms, while the dry season is characterized by cold air and light rains. Wind directions vary with seasonal meteorological conditions. Sea and land breezes prevail in the summer and occur occasionally in the spring and fall (Ref. 5). In general, fall winds occur predominantly from the east to northeast (Ref. 5).

Figure 3-3 presents the seasonal wind directions for lower atmosphere conditions at Cape Canaveral.

3.1.1.3 On-site Population

The on-site population for spacecraft launches may be considered as KSC employees and visitors. During a launch, approximately 6,000 employees and 15,000 visitors may be on-site. An additional 100 to 110 thousand spectators are often found off-site during launches of significant public interest. These individuals occupy nearby beach areas and line the public roads in the area.

3.1.1.4 Socioeconomic Factors

The KSC is located in Brevard County, which ranks eighth in size and ninth in population in Florida. Brevard County has a population density of 239 persons per square mile. The KSC and the Air Force Eastern Space and Missile Center currently employ approximately 16,000 people during the three shifts per day. This total is almost one-fourth of the Brevard County work force. The balance of the County's employment is in agriculture, tourism, and support services for KSC and other government programs.

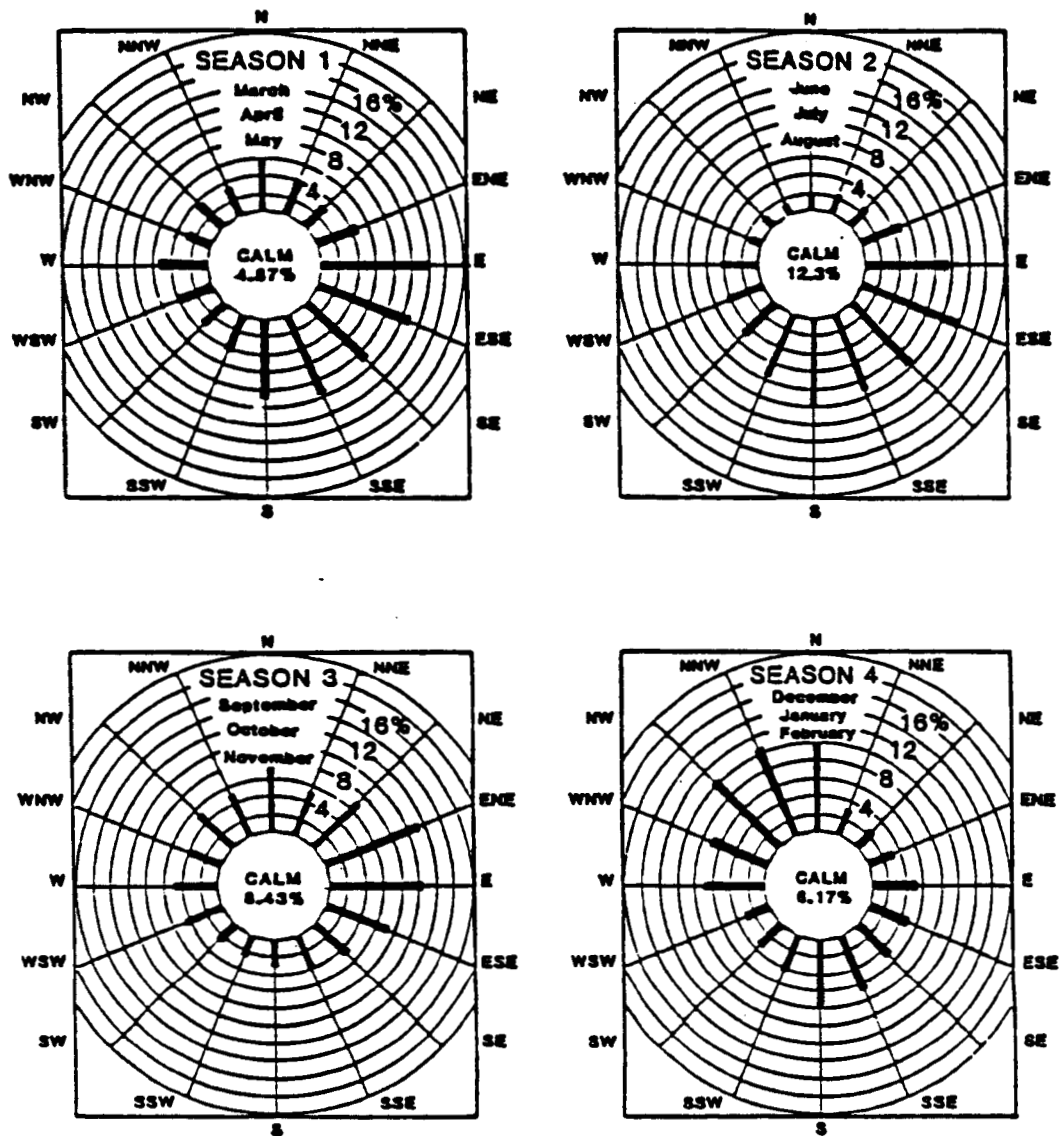


FIGURE 3-3. SEASONAL WIND DIRECTIONS - LOWER ATMOSPHERIC CONDITIONS:
CAPE CANAVERAL - MERRITT ISLAND LAND MASS

Titusville and the City of Cape Canaveral are the closest towns to the KSC industrial area. Titusville has a population of approximately 32,000 and is located 9.5 miles from the KSC. The City of Cape Canaveral has a population of approximately 5,000 and is located 8.5 miles from the KSC. The majority of KSC workers live in these two towns, as well as in Cocoa, Cocoa Beach, Melbourne, Merritt Island, and Orlando. The launches of the Space Transportation System (STS) shuttle have attracted up to an additional 100,000 to 200,000 spectators from outside the local area for launches of special interest. Spectators normally gather in several KSC on-site areas, as well as along State Route 1 near Titusville.

3.1.2 Regional

The KSC regional area consists of approximately 1,256 square miles (see Figure 3-1).

3.1.2.1 Land Uses

The KSC area encompasses 500 square miles of the Atlantic Ocean. Of the remaining 700 square miles, much of the area consists of large inland bodies of water (e.g., Indian River, Mosquito Lagoon, and the Banana River, as well as a number of ponds, lakes, and rivers) and wetland areas. The prominence of inland water bodies and wetland areas has restricted the development of residential and agricultural lands to a limited portion of the region. Population in the region is concentrated largely in two regions: along the western shore of the Indian River, and south of the KSC in the Cocoa/Rockledge and southern Merritt Island area. The western part of the KSC area consists of water, wetland, and undeveloped areas.

3.1.2.2 Hydrology and Water Use

In the sandy barrier islands that make up much of the KSC, a large part of the rainfall soaks into the ground and seeps downward to the zone of saturation of the non-artesian aquifer. Water in this zone moves laterally toward the ocean or another waterway.

Surface water is plentiful in the Cape area. The Indian River Basin in the area of Merritt Island includes many sloughs and marshes. It is estimated that about 23 percent of the land-associated surface area within 50 kilometers west of the Cape is covered by surface water.

Brevard County has productive shrimp fishing grounds. The primary species taken is the white shrimp, a migratory species that moves into and out of the area. Sought commercially are fish, shellfish, and other fisheries products. Typical commercial fish caught annually in Brevard County (Ref. 9) are shown in Table 3-1.

TABLE 3-1. ANNUAL COMMERCIAL MARINE AND ESTUARINE FISHERY LANDINGS
IN BREVARD COUNTY

Type	Pounds
Total Fish (primarily spot, tilefish, black mullet, groupers, menhadden, whiting, mackerel)	2,988,460
Shellfish (primarily scallops and crabs)	10,527,671
Shrimp	1,474,830

3.1.2.3 Population

The population in the regional area nearby the KSC is approximately 130,000. The population may increase during launches of special interest by more than 100,000 spectators, varying with the time of day and year, and the weather (see Figure 3-4). A detailed analysis of the geographical patterns of population residence and employment, as well as major transportation grids and patterns, are found in DOE's Kennedy Space Center Demographic and Land Use Study (Ref. 7).

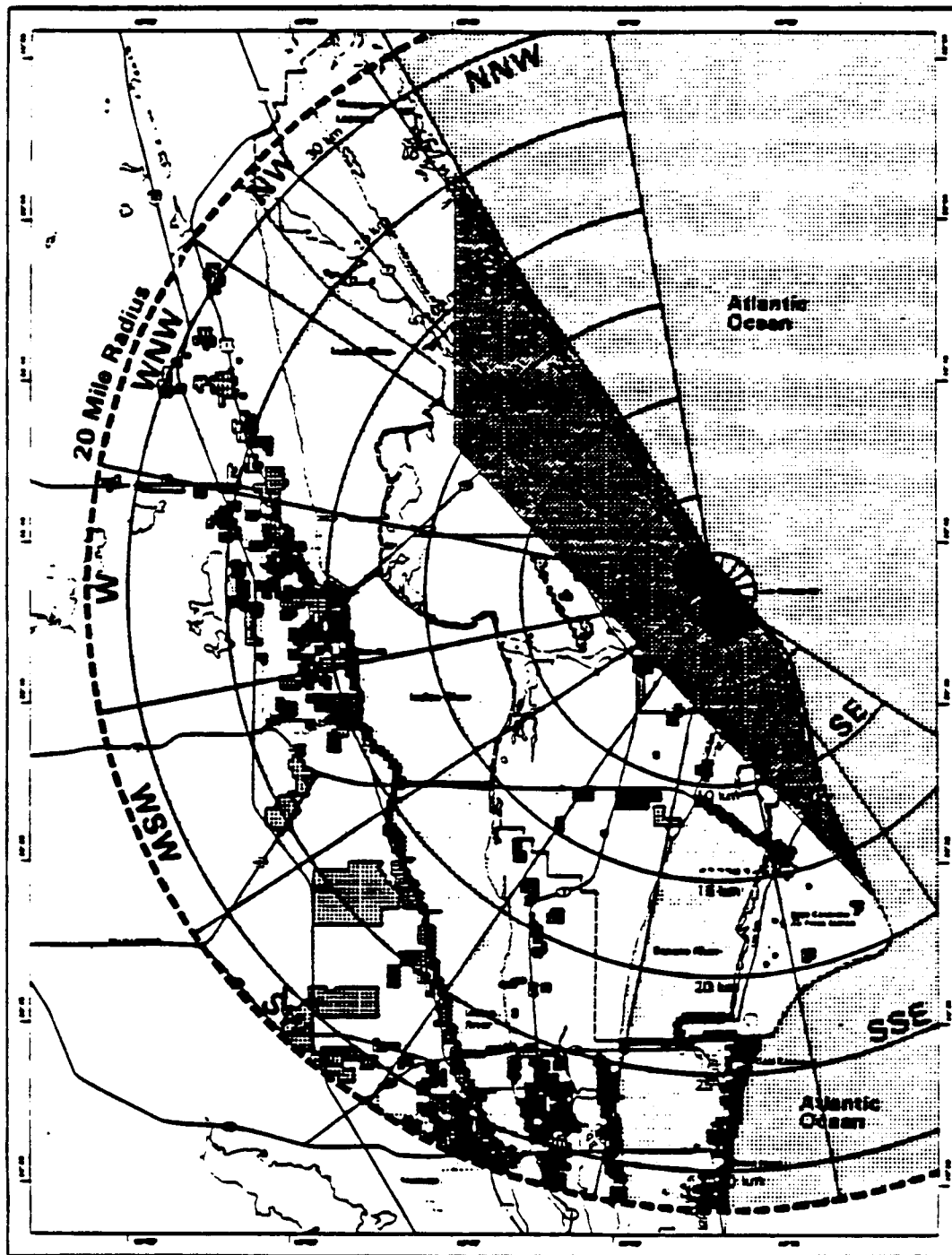
The nearest off-site population is more than 10 kilometers from the launch site and about 50 percent of the on-shore area within 20 kilometers of the launch site is water (Banana and Indian Rivers and Mosquito Lagoon). Appreciable numbers of off-site people are encountered 20 to 40 kilometers south and west of the launch site.

3.1.2.4 Additional Factors

The climate and biotic resources of the region are essentially the same as those for the local KSC area. For more information on the geography, geology, and meteorology of this region, refer to NASA's Kennedy Space Center Draft Environmental Resources Document (Ref. 5), the Kennedy Space Center Environmental Impact Statement (Ref. 6), and the Final Safety Analysis Report for the Galileo and Ulysses Missions (Ref. 9).

3.2 ABORT LANDING SITES

NASA's STS contingency plans allow for launch-abort landings at sites both inside and outside of the United States. Edwards Air Force Base, California, White Sands, New Mexico, and the KSC currently are designated by these plans as contingency landing sites within the continental United States for the Galileo and Ulysses missions. Prospective foreign landing sites are being reviewed by the U.S. State Department, and will be identified and described as a part of NASA procedures to obtain launch approval.

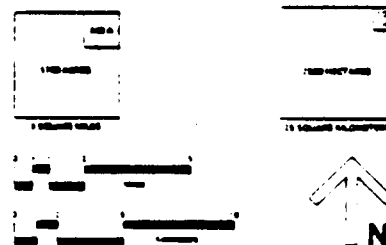


DAY LAUNCH POPULATION DENSITY WITH GRID WHEEL

Zero Population	101 - 500 People	2001 - 4000 People
Blast Danger Area (Crater)	501 - 1000 People	4001 - 6000 People
Launch Impact Limit Line (71 People)	1001 - 1500 People	6001 - 7000 People
1 - 10 People Per Square Kilometer	1501 - 2000 People	10,001 - 15,000 People
11 - 50 People	2001 - 2500 People	15,001 - 20,000 People
51 - 100 People	2501 - 3000 People	Greater than 20,000 People

01 000000

Source: Information from the Department of Defense



Kennedy Space Center Study Area

FIGURE 3-4. TYPICAL LAUNCH DAY POPULATION DISTRIBUTIONS NEAR KENNEDY SPACE CENTER

Edwards Air Force Base is located in Kern County, California, 100 miles northeast of Los Angeles. The land area of the base covers over 300,000 acres and is situated in a remote and sparsely populated area of the Mojave Desert. There are no lakes, rivers, or streams in this area, and 90 percent of the rainfall occurs between November and April. Desert wildlife is abundant (Ref. 10). Edwards Air Force Base is the prime landing site for STS Shuttle missions returning from space.

3.3 GLOBAL ENVIRONMENT

Worldwide data on meteorology, demography, and oceanography that are necessary for analyzing launch and reentry risks have been developed for DOE (Ref. 11). This information is contained in Volume 3 of the DOE Overall Safety Manual and is used by NASA, DOE, and the Interagency Nuclear Safety Review Panel (INSRP) in their various safety analyses. These data, which use a number of national and international government data sources, are currently being updated in order to broaden the data base.

4. ENVIRONMENTAL CONSEQUENCES

The principal purpose of this Final (Tier 1) Environmental Impact Statement (EIS) is to present information to enable a choice among the alternatives presented in Section 2. This section discusses the potential environmental consequences that could result from the implementation of each of the programmatic alternatives available to the National Aeronautics and Space Administration (NASA) as presented in Section 2. Implementing any of these choices has no near-term environmental impacts. The only potentially significant environmental consequences are associated with the completion and operation of the missions (i.e., the launch or inadvertent reentry). Therefore, the present EIS treats the launch implications in at least a preliminary way, recognizing that a subsequent decision on a launch of each mission is required. Those decisions will be based on:

- Detailed analyses and a safety verification test program documented in a Final Safety Analysis Report (FSAR) for each mission
- An independent safety evaluation documented in a Safety Evaluation Report (SER) prepared for each mission.

Each launch decision will be made in accordance with a Presidentially mandated launch approval process. In accordance with its own regulations, NASA will prepare additional updated environmental analyses for the Galileo and Ulysses missions which will have the benefit of the detailed information developed in the FSAR.

The primary environmental concern associated with the Galileo and Ulysses missions is the possibility of environmental impacts associated with potential major accidents involving launch or accidental reentry of the spacecraft.

The only expected environmental consequences are associated with the normal launch of the Galileo and Ulysses missions. The environmental consequences of normal operations and normal launches were discussed in detail in the previously published EISs on the Space Shuttle Program (Ref. 10), the Kennedy Space Center (KSC) (Ref. 6), and the KSC Environmental Resource Document (Ref. 5), and are summarized in Section 4.5.

It is important to note that adoption of the proposed action at this time does not irrevocably commit NASA to a future course of action. In particular, there will be a subsequent, separate decision among alternatives to launch, delay, or cancel one or both of the missions based on safety, environmental, and programmatic considerations. Furthermore, the modifications to the spacecraft will not preclude a later decision to switch from the Space Transportation System (STS)/IUS configuration to a Titan IV/IUS configuration.

4.1 ENVIRONMENTAL CONSEQUENCES OF THE PROPOSED ACTION TO CONTINUE WITH MODIFICATIONS OF THE SPACECRAFT TO USE THE IUS WHILE COMPLETING THE FSAR AND ADDITIONAL NEPA RELATED DOCUMENTATION

This section discusses the consequences associated with the proposed action of continuing development of the Galileo and Ulysses missions (i.e., continuing with the modifications to the Galileo and Ulysses spacecraft to pursue the option of an STS/IUS launch in 1989 and 1990, respectively) while conducting the detailed analyses of the safety and environmental consequences of launch and missions execution. No immediate or near-term environmental impacts are associated with adopting the proposed action.

Figure 4-1 shows the activities of the Galileo project necessary to enable a launch in October/November 1989. These activities fall into three general categories: problem resolution, new mission requirements, and launch vehicle. Under problem resolution are a series of activities that grew out of the testing program conducted in preparation for the 1986 launch. These problems and their resolution are unrelated to the change in mission, but the launch delay presented an opportunity to increase the reliability of the spacecraft systems (i.e., reduce the risk of their malfunctioning). New mission requirements are those activities associated with preparation for the VEEGA trajectory (e.g., added thermal insulation for operation within 1 AU).

These activities themselves have no significant environmental impact. Further, these activities neither presuppose nor obviate any of the alternatives. Specifically, both the continue and delay alternatives contain options for use of the IUS.

There are no environmental consequences associated with continuing the program development while the safety analyses and additional NEPA related documentation. The major activities to be conducted before the additional NEPA related documentation is completed and issued involve making modifications to the Galileo spacecraft to accommodate the IUS and adding thermal insulation to protect the Galileo spacecraft on its path to Jupiter. Only minor modifications to the Ulysses spacecraft will be necessary. For Galileo, these activities will occur at the Jet Propulsion Laboratory (JPL) and will involve existing employees, use existing building space, and require no significant additions of materials. No significant environmental impacts have been identified as associated with these changes. None of the changes will preclude a later decision to switch from the STS/IUS configuration to launch vehicle alternatives such as the Titan IV/IUS.

4.2 ENVIRONMENTAL CONSEQUENCES OF SUSPENDING MODIFICATIONS UNTIL AFTER THE FSAR AND THE ADDITIONAL NEPA RELATED DOCUMENTATION ARE COMPLETE

There is no environmental benefit from suspending modifications to the Galileo spacecraft because there are no adverse environmental impacts associated with those modifications. On the other hand, there are both near-term and longer-term potential consequences of suspending modifications to the Galileo and Ulysses spacecraft until after the FSAR and additional NEPA related documentation are completed. The near-term impacts are expected to be principally scientific, economic, programmatic, socioeconomic, and geopolitical.

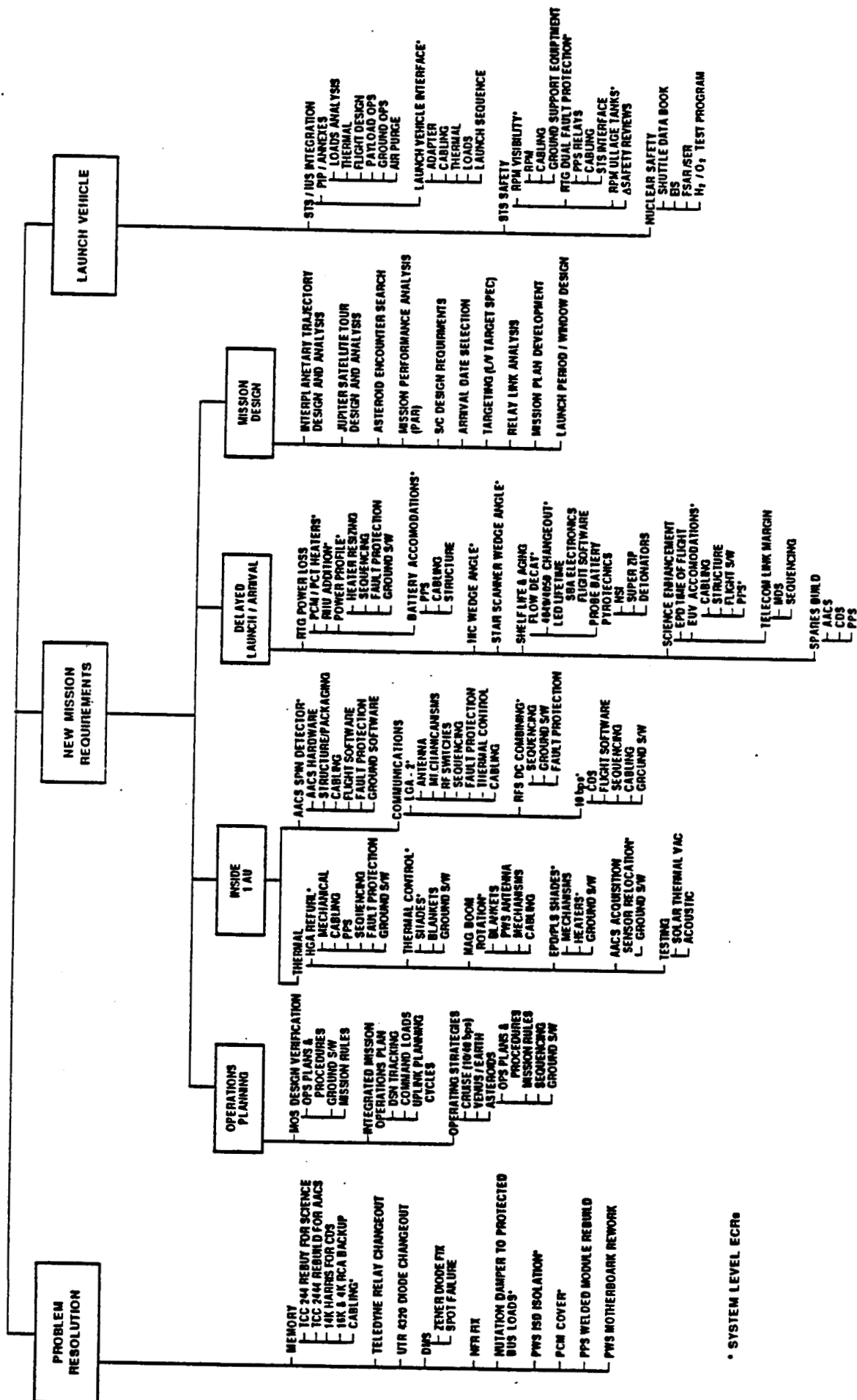


FIGURE 4-1. GALILEO DEVELOPMENTAL ACTIVITIES

The Galileo Mission was started in October 1977 and originally was scheduled for launch in 1982. It has been the highest priority objective of NASA's Solar System Exploration Program for about 10 years. A further delay would have a significant negative impact on the science program.

Although no modifications per se are being carried out on the Ulysses spacecraft, the recertification test program for the spacecraft starts in early 1989, and a delay of the recertification test until after the issue of the FSAR (September 1989) would rule out a 1990 launch. Currently, about 500 people are working at JPL and elsewhere on the Galileo and Ulysses missions. If the modifications of the spacecraft were delayed a year or more until completion of the FSARs and the additional NEPA related documentation, there would be major programmatic impacts. Attempting to retain critically skilled personnel on a standby basis would be inordinately expensive. On the other hand, releasing such personnel and later attempting to hire replacements would undoubtedly lead to delays that would threaten the 1991 launch opportunity. Although NASA could eventually regain the skills, NASA would lose the experience base of the current staff.

Services requirements would also add expense to the mission. To minimize system deterioration, the spacecraft would have to be serviced periodically (e.g., to keep bearings and mechanisms operable).

4.3 CONSEQUENCES OF CANCELLING ONE MISSION AND PROCEEDING WITH THE OTHER

No near-term benefits would result from cancellation because the proposed action involves no environmental risk. However, the cancellation of either the Galileo or Ulysses mission would result in a loss of the scientific benefits intended by the programs. Cancellation does avoid the possible radiological risks that may be associated with a launch. Such possible risks will be known and analyzed more fully in the FSAR and additional updated environmental analyses. The preceding alternatives will neither presuppose or obviate a later decision to cancel. Not cancelling the missions will not obligate the program to an exposure to such risks because the actual launches will be the subject of separate decisionmaking processes.

4.3.1 Consequences of Cancelling Galileo

There are no near-term environmental benefits of cancelling the Galileo mission, but there are major economic, programmatic, and geopolitical consequences of such a cancellation. Through FY 1987 (i.e., through September 30, 1987), NASA will have expended approximately \$735 million on the Galileo program. Cancellation would mean the abandonment of that investment and a loss of the anticipated scientific gains.

Currently, the United States has a clear lead in the exploration of the outer planets. Programmatically, there are currently no back-up missions that could achieve Galileo's scientific goals within this century, as there are no other approved U.S. missions to the outer planets. Thus, the United States would forego detailed scientific knowledge of the unique environments of Jupiter.

Galileo was started in 1977 and many scientists, engineers, and technicians have devoted a large share of their professional lives working on this project. From a human standpoint, it would be unfortunate to cancel the program when there is no clear evidence at this point of adverse environmental impacts that would justify such a cancellation.

4.3.2 Consequences of Cancelling Ulysses

There are no near-term environmental benefits associated with cancelling the Ulysses mission, but there are major economic, programmatic, and geopolitical consequences. Through FY 1987, NASA will have expended approximately \$135 million on the Ulysses program. The European Space Agency (ESA) also will have spent at least that amount. That investment will be lost if the Ulysses program is cancelled.

Programmatically, Ulysses is the only approved, or even planned, mission to study the polar regions of the Sun. In addition, Ulysses will contribute significantly to the proposed Global Geospace Science (GGS) initiative involving the United States, the ESA, and Japan. If the U.S. participation in Ulysses is cancelled, the United States may appear as an unreliable partner for joint space exploration programs.

4.4 CONSEQUENCES OF THE NO ACTION ALTERNATIVE - CANCELLING BOTH MISSIONS

The cancellation of the Ulysses and Galileo missions would result in the loss of the scientific benefits intended by these missions. Since there are essentially no risks involved in the proposed action, cancelling the missions will have no near-term benefits. However, cancellation does avoid the possible radiological risks that may be associated with a launch. Not cancelling the missions will not obligate the program to an exposure to such risks because the actual launches will be the subject of separate decisionmaking processes.

On the contrary, cancelling both missions will result in an additive combination of the adverse economic, programmatic, and geopolitical consequences of the cancellation of each mission separately. For instance, the United States would be abandoning an investment of \$870 million.

Further, since the Federal Republic of Germany is a partner in Galileo and the ESA is a partner in Ulysses, cancellation of both missions would critically threaten the ability of the United States to participate in international cooperative programs in the future.

4.5 CURRENT UNDERSTANDING OF IMPLICATIONS OF LAUNCH OF MISSIONS

4.5.1 Implications of Normal Launches

4.5.1.1 Implications of Normal Launches of the STS/IUS

The potential environmental impacts associated with the normal launch of the STS were identified in the previously published EISs on the Space Shuttle Program (Ref. 10), the KSC (Ref. 6), and the KSC Environmental Resource Document (Ref. 5). These potential environmental impacts (Ref. 10) are summarized below.

Troposphere

A ground cloud will be formed by the Space Shuttle rockets during launch. This cloud consists of the exhaust products from the solid rocket motors and liquid engines, the products of afterburning in the exhaust plume, the air that is mixed with the exhaust gases, and much of the heat energy that is generated. These gases have the potential for forming high concentrations of acids that can rain on and affect vegetation.

The direction, movement, and diffusion of the ground cloud have been the subject of an intensive analytical study that has been conducted during the past several years. A mathematical model (the Rocket Exhaust Effluent Diffusion Model) has been developed that uses the characteristics of the rocket exhaust products and launch site meteorology to predict the rise, growth, and dispersal of the ground cloud. To validate the model, seven Titan launches were monitored at the KSC, using aircraft-based, ground-based, and sea-based instrumentation to measure cloud concentrations and fallout of hydrogen chloride, carbon dioxide, and aluminum oxide particles. These chemicals are the primary exhaust products of the solid rocket motors that are of concern. In all cases, reasonable agreement exists between measurements and the model predictions.

Theoretical predictions for 45 hypothetical Shuttle launch cases, solid motors and liquid engines firing simultaneously, provided concentrations of hydrogen chloride that were below the recommended exposure limits. The largest peak concentration of hydrogen chloride calculated was 3.9 parts per million (ppm), and the highest average exposure level over a 10-minute period was 1.2 ppm. The human exposure limit for hydrogen chloride recommended by the National Academy of Sciences (NAS) is 4 ppm for a 10-minute period with a peak of 8 ppm.

The hydrogen chloride emitted from the solid rocket motors also can produce acidic rain if the Space Shuttle is launched during certain local meteorological conditions. In 1967, Aerojet General Corporation tested a 260-inch solid rocket motor during local shower activity, which resulted in damage to lime groves in the area. Acidic rainfall was measured for the first time during the Titan/Viking-B launch in September 1975, and pH values ranging from 1 to 2 were measured in areas close to the launch complex. The exhaust products contained in the ground cloud typically are dispersed within a 9-mile zone around the launch site. Up to 6,615 lbs of chlorides and 15,435 lbs of particulates are deposited in the near field environment, with the heaviest deposition usually occurring within 0.6 mile of the launch site. Actual deposition of up to 100 g/m² of chlorides and 200 g/m² of particulates have been collected from the near field zone (Ref. 5).

Sonic Boom

Launch of the STS results in three sonic booms with focal zones over uninhabited ocean waters (Ref. 5). The first, and largest sonic boom, occurs with ascent of the STS and generates a maximum overpressure of 3.66 pounds per square foot (psf). The focal zone of this boom is typically located about 40 miles offshore of the launch site in the Atlantic Ocean. Atmospheric reentry of the jettisoned SRB's generates the second sonic boom with maximum overpressures of 2 to 3 psf. The focal zone of this boom is located 150-200 miles down range. The third sonic boom occurs with reentry of the jettisoned external tank. The focal zone is located over the Indian Ocean and has a maximum overpressure of 2 to 4 psf.

The Orbiter also will produce a sonic boom during reentry. Because of the large range of entry trajectories, the boom may occur partially over land. Overpressures have been calculated for these conditions, and trajectories have been tailored to minimize the effect on the ground. Studies are being conducted in this area, and current estimates indicate that maximum overpressures will be about 96 N per square meter (2 pounds per square foot) in a small area within about 48 kilometers (26 nautical miles) of the landing site. Sonic boom measurements were recorded for four landings at KSC (Ref. 5). A maximum overpressure of 2.2 psf was recorded from these landings at Titusville about 10 miles from the Shuttle Landing Facility at KSC. These overpressures are in the nuisance or annoyance range according to the report issued by the Sonic Boom Panel of the International Civil Aviation Organization in October 1970.

Stratosphere

The Space Shuttle exhaust releases water, hydrogen chloride, chlorine, and aluminum oxide particles into the stratosphere and produces nitric oxide in the hot plume. The quantity of water released by the Space Shuttle is small compared to natural sources, and its effect on the ozone density will be insignificant. Model calculations of the effects of aluminum oxide and nitrogen oxides have been made, and the results indicate that the effects of these oxides also are negligible. Chlorine compounds in the exhaust are the major source of STS impact on stratospheric ozone.

The potential effect of Space Shuttle emissions on the stratosphere was evaluated using the projected Space Shuttle launch rate, projected to peak at a steady state of 60 flights per year (current projections are much lower). This launch rate was used in a one-dimensional model to predict hemispherically averaged chlorine concentrations as a function of altitude and time.

From calculations made during different studies conducted by six independent scientific groups in late 1976, the maximum steady-state reduction of ozone was estimated to be 0.2 percent for 60 STS launches per year (Ref. 10). Later in 1977, it was established that the $H_2 + NO \rightarrow OH + NO_2$ reaction rate occurred much faster than was previously supposed. This reaction rate is significant in stratospheric ozone chemistry, and a larger value leads to a larger ozone reduction effect. New calculations in 1977 by five independent groups, using the same models but with the new reaction rate, indicated that the average ozone reduction in the Northern Hemisphere would be about 0.25 percent for 60 STS launches per year. This is slightly

higher than the previous value. This is considered insignificant and undetectable compared to the much larger natural variations in stratospheric ozone levels, and should result in no long-lasting or permanent change for the stratosphere.

Ionosphere

During Orbiter maneuvers above an altitude of 180 kilometers, the exhaust products from the Orbital Maneuvering System (OMS) will reduce the ion concentration. This effect is localized and temporary. Effects on radio wave propagation will be insignificant.

During Orbiter reentry, which will occur between a 70- and 90-kilometer altitude, some of the heated atmosphere will be converted to nitric oxide, which ionizes in ultraviolet sunlight. The length of the trail could extend to one-fourth the circumference of the Earth, but the width will be narrow. The required time for the trail to disappear has been calculated to be less than 1 day, and if wind shears are present, the trail could disappear in hours. The effects of the ionized trail on radio wave propagation are expected to be insignificant. The long-term effects of the nitric oxide on the stratosphere also have been studied and have been determined to be negligible.

Health and Biological Effects

The impact of the Space Shuttle on the tropospheric regions of the atmosphere will have no significant medical (human) or biological (plant and animal) effects outside the KSC. A baseline (or library) of existing flora and fauna has been developed to differentiate between the seasonal, climatic, and other changes (natural or manmade) occurring at the KSC launch site.

The launch-generated ground cloud has a measurable impact on the near field flora and fauna of the launch site. Near field impacts from launch events include acute vegetative damage and fish kills (Ref. 5).

Information on the impacts of launch events to the local environment has been documented from a 54-acre area outside of the perimeter of Launch Complex 39A (LC-39A). Described as within the near field environment, this tract has experienced significant changes in vegetative community structure (Ref. 5). Vegetation surveys over nine launch events (April 1981 - November 1983) documented a reduction in species richness accompanied by the elimination from the tract of sensitive species. Shrubs and small trees exposed to the launch blast and associated ground cloud suffered defoliation and with time gradually were reduced or replaced by grasses, sedges, and weedy herbs. Overall, total vegetative cover in the near field have been reduced and unvegetated areas have expanded.

The launch of STS-8 (August 1983) and STS-9 (November 1983) resulted in damage to the coastal dune community. Impact analyses indicate that thin-leaved herbaceous species, and shrubs with succulent leaves, are more sensitive to launch cloud deposits than are typical dune grasses (Ref. 5). Dune community species exhibiting sensitivity to launch cloud effects include camphorweed (*Heterotheca subaxillaris*), inkberry (*Scaevola*

plumieri), beach sunflower (Helianthus debilis), and marsh elder (Iva imbricata). Dune species exhibiting resistance to launch cloud effects include sea oats (Uniola paniculata), beach grass (Panicum amarum), and slender cordgrass (Spartina patens).

Shallow impounded waters in the vicinity of LC-39A have experienced fish kills following the launch of the space shuttle system (Ref. 5). These waters can experience sharp depressions in pH as a result of launch cloud rainout. Reductions in pH of 4 units within 30 minutes of a launch event are possible.

The sudden acidification of surface waters is believed to be responsible for the fish kills accompanying launch events. Species of fish collected from the near field impact area exhibit symptoms of severe ionic imbalance and anoxia, resulting from extensive gill damage (Ref. 5).

Fish kills have ranged from small (less than 100 individuals) to major (greater than 1,000 individuals). To date, a total of 17 species have been recorded from the near field impact zone with individual specimens typically less than 2 inches in length. The species recorded are fairly typical of those expected to occur in open water salt marsh habitat.

While the impact on the near field flora and fauna is measurable following each launch event, these impacts are localized and are not likely to extend significantly from the near field environment.

Shuttle exhaust gases do contribute to the depletion of ozone in the stratosphere; however, such impacts occur over the ocean in a limited and small area. The natural ultraviolet irradiances are highly variable and exceed the Shuttle-predicted ozone change by one order of magnitude. The responses and the repair rate of organisms to given doses and dose rates of ultraviolet radiation also are highly variable. These factors make any prediction of the effect of such a small increase in ultraviolet radiation on skin cancer highly questionable.

Occupational Exposure Due to Normal Launch

Exposures of occupational personnel to minor external radiation would occur during the transportation and handling of the Radioisotope Thermoelectric Generators (RTGs) before launch. Exposure levels are monitored to ensure that the range is within acceptable limits, and the installation procedures are carefully designed so that the expected exposure levels are as low as reasonably achievable.

4.5.1.2 Implications of Delayed Normal Launches

For a launch of Galileo and Ulysses to occur in the next available delayed opportunity, 1991, two launch configurations are potentially possible, the STS/IUS discussed in the previous section, and a Titan IV/IUS configuration. The potential environmental impacts associated with normal launches of the STS/IUS were discussed in Section 4.5.1 and would not be significantly different if the launches were delayed until 1991.

The environmental implications of a normal launch of a Titan IV/IUS have been addressed by the U.S. Air Force (Ref. 27). (The Complementary Expendable Launch Vehicle or Titan 34D7 evaluated in Reference 27, has subsequently been renamed the Titan IV.) The impact evaluations for the Titan IV (Ref. 27) were generally based upon scaling-up from those addressed in an earlier NEPA document prepared for the Titan III (Ref. 26). Environmental impacts for Titan IV launches are qualitatively similar to launch impacts of the STS, but are expected to be quantitatively different. The Titan IV Solid Rocket Motors (SRMs), for example, use approximately 60 percent less solid rocket propellant than the STS and hence produces a proportionately smaller exhaust cloud. The thrust-to-weight ratio for the Titan IV vehicle is significantly higher than that for the STS. This will allow the Titan IV vehicle to accelerate more quickly and clear the launch pad in less time, producing a smaller ground level exhaust cloud. A third significant difference between the Titan IV and the STS is the type of engines used during the initial lift-off. Unlike the STS, lift-off of the Titan IV vehicle will be accomplished through use of only the two SRMs. The liquid propellant stages do not ignite until approximately 115 seconds after lift-off. One effect of the faster lift-off coupled with the lack of liquid engine exhaust for the Titan vehicles versus the STS is that less HCl from the solid rocket motor exhaust will be scrubbed out of the low altitude exhaust cloud to form HCl mist. Updated consequences for the Titan IV launch vehicle, as an alternative to the STS/IUS launch vehicle, will be addressed as needed in the additional environmental analyses that will be prepared prior to the launch of each mission.

Minor external radiation exposures of occupational personnel would occur during the transportation and handling of the RTGs before launch. No significant increase in occupational doses is anticipated between the 1986 projection and that expected for a 1991 launch window.

4.5.2. Current Understanding of Potential Consequences Associated with Possible Accidents

An analysis of the impacts of possible accidents involving the Galileo and Ulysses spacecraft must consider the following two contributing factors: 1) the response of the RTG assembly and its General Purpose Heat Source (GPHS) modules to potential accident environments, and 2) the influence of various launch vehicle configurations on the severity of damage that may be done to the RTG assembly as a result of explosions or impacts encountered in an accident environment. These issues are addressed in the following subsections.

4.5.2.1 RTG and GPHS Design and Performance History

The GPHS, which is the source of energy for the Galileo and Ulysses RTGs, is the culmination of almost 25 years of design evolution of heat source technology. Safety is a principal engineering design goal of the heat source. The safety-related design goals are to: 1) contain or immobilize the fuel to the maximum extent possible under normal and accident environments, and 2) ensure compatibility with the power generation system. The following is a summary (see Ref. 25) of safety environments and GPHS response:

- Liquid Propellant Fires. The GPHS modules survive the most severe fires that can result from on-pad events.
- Solid Propellant Fires. The GPHS survives fires in contact with the burning solid propellant.
- Explosions. Modules were shown to survive up to 500 psi overpressures and clads were shown to survive pressures in excess of 2,000 psi.
- High-velocity Fragments. Test data for bare fuel clads impacted by flyer plates representative of structures involved in External Tank (ET) explosions (i.e., aluminum of thicknesses of approximately 3.5 mm) were only minimally breached at velocities up to 1,170 m/s (3,838 f/s).
- Reentry. GPHS modules survive Earth-escape-velocity-reentry ablation, and thermal stress with wide margins. The very remote possibility of an Earth flyby velocity reentry is currently under study. The results of the navigation study are presented in this EIS. The results of the reentry aerothermodynamic study will be presented in the Galileo Mission EIS (Tier 2).
- Earth Impact. GPHS modules were designed to survive impact on hard surfaces (granite/steel/concrete) at terminal velocity; 54 m/s (175 f/s). Test results show no failures of clads against sand up to 250 m/sec (applicable to 98 percent of the Earth's surface), no clad failures against concrete at terminal velocity (54 m/s), and small releases against steel or granite at terminal velocity. Even though clads alone showed small release when impacting at terminal velocity on a hard surface, when protected by the aeroshell and graphite impact shell, the normal configuration, no release would be expected to occur.
- Ocean Impact. GPHS modules survive water impact and will resist fuel release for virtually unlimited periods.

The design features for the GPHS incorporate many safety-related considerations. The fuel used in the GPHS design is plutonium 238 dioxide, high-fired and hot-pressed into 62.5 Watt capacity ceramic fuel pellets. In this form, plutonium 238 is virtually insoluble in ground or sea water should such exposure occur.

The primary protective material used to encapsulate the fuel is an alloy of iridium. Iridium is a unique noble metal found in deposits of gold and platinum. It is compatible with the fuel material to over 1,500°C (2,700°F), resists oxidation in air to 1,000°C (1,800°F), and melts at 2,447°C (4,437°F). Each clad also contains a frit vent designed to release the helium generated by the fuel alpha particle decay and to prevent the release of plutonium.

The graphitic materials in the GPHS perform several functions. The primary function is to provide reentry protection for the fueled clads. This is the job of the aeroshell. A second major function is impact protection. This is accomplished by both the aeroshell and the impact shell. The impact shell also serves as a redundant reentry aeroshell. The

third function is to provide a mounting structure for the clads to survive normal ground handling and launch dynamic loads. The material used for the aeroshell and impact shell is called fine weave, pierced fabric (FWPF). FWPF is a carbon-carbon composite material woven with high-strength graphite fibers in three perpendicular directions. Upon impregnation and graphitization, the material has an extremely high thermal stress resistance as required for reentry protection. FWPF has a very fine structure that results in uniform ablation characteristics leading to high confidence in ablation margins. This material, used primarily by the Air Force for missile nose cones, is one of the best available for reentry applications.

The GPHS deliberately was designed to be composed of small, modular units so that reentry heating and terminal velocity would be lower than they were for previous heat sources. A modular heat source tends to minimize the amount of fuel that can be postulated to be released in a given accident. For example, for a high-velocity fragment impact resulting from a severe explosion that penetrates the GPHS, at most a few of the fueled clads would be expected to release fuel. This is an improvement over earlier heat source designs. Modularity also simplifies and reduces the cost of the development and safety test programs.

Overall, the Department of Energy (DOE) has spent 9 years in engineering, safety, and environmental testing of the GPHS, building on the experience gained from previous heat source development programs.

There have been three U.S. spacecraft that failed to achieve their intended mission that included RTGs onboard the spacecraft. Early RTG models carried relatively much smaller amounts of nuclear material and were built to burn up at high altitude during accidental reentry. This design requirement was met in 1964 during the malfunction of the Navy's Transit-5BN-3 navigational satellite which carried the SNAP 9A RTG. There have been no known health effects from the loss of this satellite.

Since 1964, RTG systems have been designed for full fuel containment in the event of an accident. This design philosophy has performed flawlessly in two mission failures where RTGs were present. A SNAP 19B2 RTG landed intact in the Pacific Ocean in May 1968 after a Nimbus B weather satellite failed to reach orbit. The fuel was recovered and used in a later mission. In April 1970, the Apollo 13 lunar module reentered the atmosphere and its SNAP 27 RTG, which was jettisoned prior to reentry, fell intact into the 20,000 feet deep Tonga Trench in the Pacific Ocean, as planned for in an aborted mission in such a situation.

4.5.2.2. STS/IUS Configuration

In the wake of the Challenger accident, NASA cancelled development of the Centaur G-Prime for flight crew safety reasons unrelated to nuclear launch safety. That rocket was an energetic liquid hydrogen/liquid oxygen upper stage launch vehicle. In its place, NASA proposes to use the solid fueled IUS in the Shuttle for launching deep space missions such as Galileo and Ulysses. An IUS successfully deployed a Tracking Data Relay Satellite in Earth Orbit during the successful September 1988 STS Discovery flight.

The STS/IUS configuration is expected to pose much less potential environmental risk than the STS/Centaur, which was addressed in the draft EIS of September 1985 (Ref. 1). The earlier STS/Centaur safety analysis indicated that most accident environments were dominated by Centaur involvement irrespective of the initiating cause (e.g., a Solid Rocket Booster (SRB) rupture would generate high-velocity fragments that would cause a Centaur rupture and explosion). The IUS, a solid fueled upper stage whose fuel is more inert, is much less likely than the Centaur to explode and contribute to accident environments.

It is noteworthy that an IUS upper stage was on board during the Challenger accident in order to propel a data relay satellite to geosynchronous orbit. Detailed examination of photographic records, telemetry data, and fragments recovered from the Challenger accident have shown that: 1) no major explosion occurred, rather a rupture of the external propellant tank, initiated by the effects of the Shuttle booster joint failure, was followed by release and rapid burn of some of the liquid propellants; 2) the Shuttle Orbiter subsequently broke up under flight dynamic and aerodynamic forces; and 3) the IUS booster came out of the cargo bay relatively intact, broke up under aerodynamic forces, and fell 50,000 feet to the ocean surface without violent solid propellant ignition. Uncertain photographic evidence and an incomplete recovery of the Tracking and Data Relay Satellite did not permit an assessment of its response sequence.

These findings indicate that the IUS did not contribute to the accident environment. Also, based on the general design of the RTG, it is reasonable to infer that had an RTG been on board the Challenger with an IUS, it would not have been damaged significantly in the accident, and therefore, it is expected that there would have been no release of plutonium.

Available Information

The detailed safety analyses, environmental analyses, and the safety verification test program are underway for the STS/IUS configuration, but are not yet complete. Still, the existing data base from past analyses, performance data and flight experience from earlier missions, and early results of the current analyses provide sufficient information to assess the adoption of the VEEGA trajectory and to make preliminary assessments of the consequences of accidents for the STS/IUS case, and to assess the implications of unavailable data.

The kinds of information available are: 1) safety and environmental analyses for the STS/Centaur, 2) revised estimates for the most significant accident scenarios for the STS/IUS configuration, 3) results of earlier and continuing tests of the response of the RTG to various accident environments, and, 4) preliminary results and assessments of ongoing safety and environmental analyses being conducted in preparation for the launch approval review process and the additional updated EISs (Tier 2). These information sources, inferences made from these sources, and their limitations are discussed below.

The safety and environmental analysis processes are depicted in Figures 4-2 and 4-3. The analyses consist of defining potential accident scenarios and resulting environments to which the RTGs/Radioisotope Heater Units (RHUs) may be exposed and the probability distributions of these accidents.

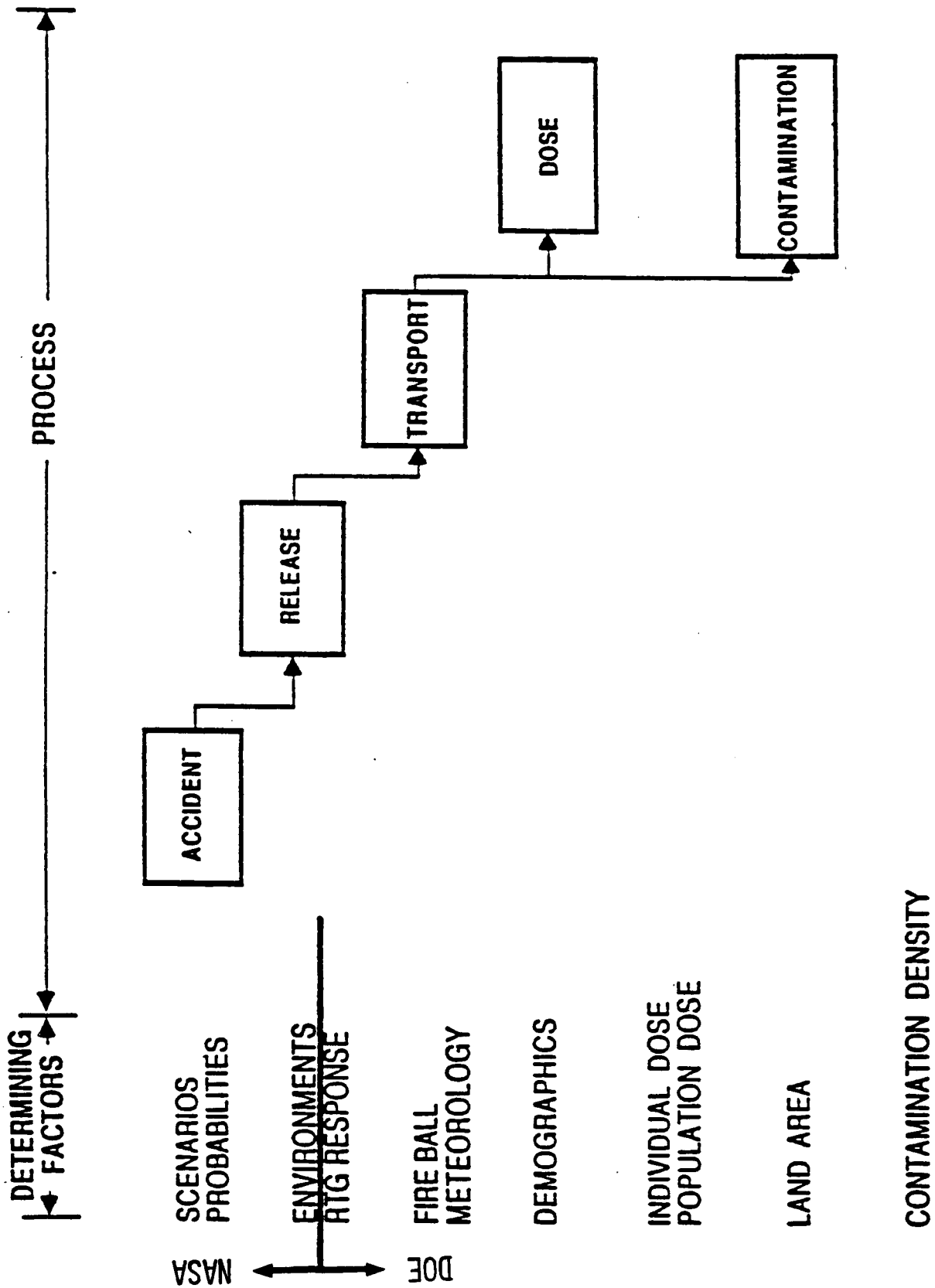
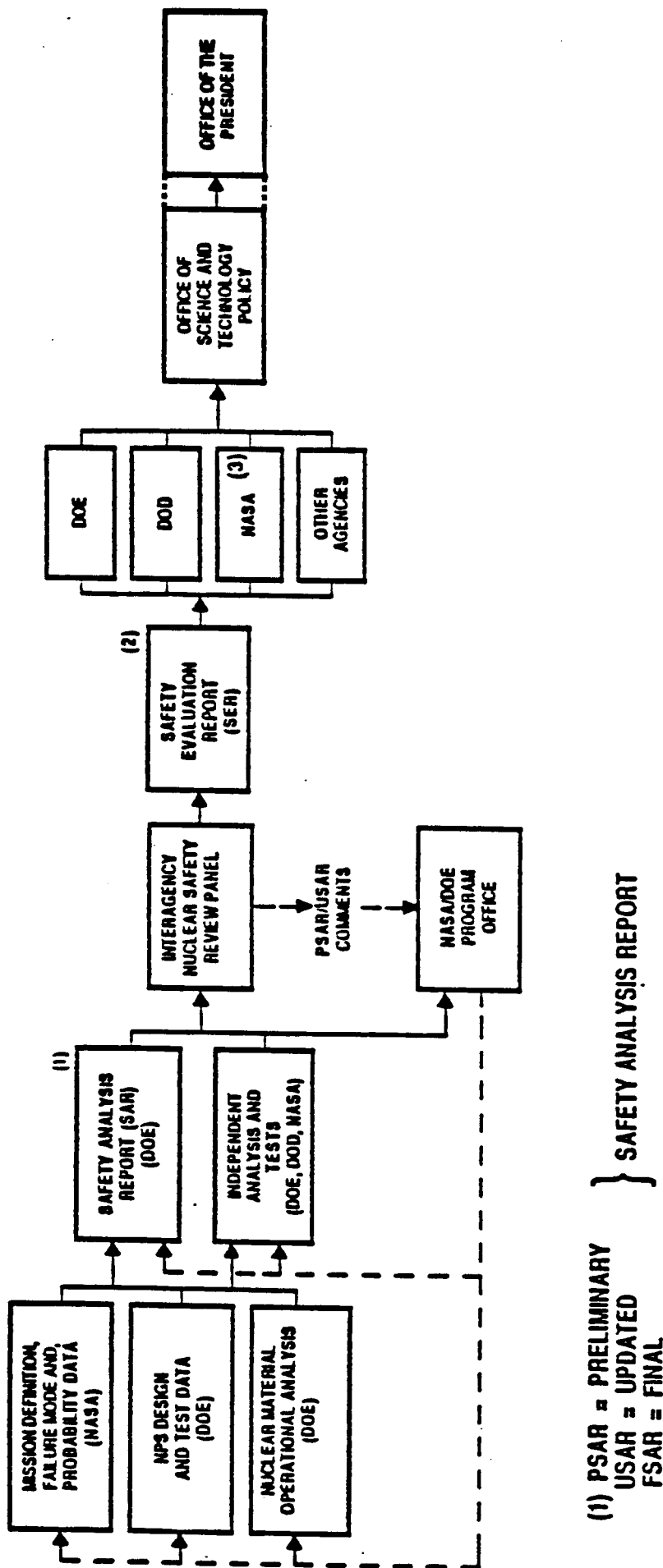


FIGURE 4-2. SAFETY AND ENVIRONMENTAL ANALYSIS PROCESS



- (1) PSAR = PRELIMINARY
USAR = UPDATED
FSAR = FINAL
- (2) SAFETY ANALYSIS REPORT
- (3) SAFETY EVALUATION REPORT WRITTEN BY NSRP BASED ON FSAR REVIEW AND INDEPENDENT ANALYSIS
- (3) RESPONSIBLE MISSION AGENCY MUST MAKE LAUNCH RECOMMENDATION BASED ON REVIEW OF FSAR AND SER

FIGURE 4-3. AEROSPACE NUCLEAR SAFETY REVIEW PROCESS

and environments, and then assessing the consequences of subjecting the RTGs/RHUs to those environments. The risk is then a combination of the probabilities of the accidents and their consequences. At this time, there is a Shuttle Data Book (Ref. 28) that contains scenarios and environments for the STS/IUS configuration.

A number of documents were developed for the planned 1986 launch of Galileo and Ulysses using the STS/Centaur. Among these documents were: the FSAR (Refs. 12, 13, and 9); a draft SER (Ref. 14) prepared by the Interagency Nuclear Safety Review Panel (INSRP) but never formally completed due to cancellation of the STS/Centaur; and the "Assessment of the Safety Documentation for the Galileo and Ulysses Mission" prepared by the DOE Office of Nuclear Safety (Ref. 15).

During the interval between the completion of the FSAR (late 1985) and the present, work has been redirected to develop and to improve and refine the accident models and techniques for analyses applicable to the STS/IUS case as follows.

Liquid propellant explosion modeling for ET accidents has been completely redone. The STS/IUS liquid propellant explosions involve spill modes onto the launch pad from the ET or in-flight vapor cloud explosions. Data have been reevaluated and recent cryogenic mixing data allowed estimation of reactant density and improved estimates of explosion parameters at the location of the RTGs for the accident scenarios.

GPHS safety testing is continuing, and additional test data that will be used in the STS/IUS FSAR are being obtained.

An atmospheric dispersion model that is able to use multiple sequences of real time varying three-dimensional meteorological data, and having a sea breeze modeling capability, has been adapted for FSAR use (Ref. 16).

While the 1985 FSAR represented a significant increase in the sophistication of accident modeling over that applied for previous RTG missions, the activities described in the preceding paragraphs since the 1985 FSAR will permit a better assessment of mission risks.

A new FSAR and SER will be required for the STS/IUS because the analysis of December 1985 is not applicable to the present case. In the earlier analyses, the accident scenarios with appreciable release of fuel all assumed that the Centaur explosive blast was high enough in overpressure and impulse to strip away the aeroshell and hurl iridium encased fueled clads against the Shuttle bay forward bulkhead. With replacement of the liquid-fueled Centaur with the solid-fueled IUS, these accident scenarios no longer apply. Therefore, most of the accident analyses and the results of the earlier STS/Centaur FSAR are not relevant to the STS/IUS configuration.

STS/IUS Configuration Assessment

The STS/IUS (and STS/IUS/PAM-S) will present much more benign accident environments than did the STS/Centaur. The IUS is much less likely than the Centaur to contribute to accidents initiated elsewhere. For instance, the December 1985 FSAR assumed that an ET explosion would lead to fragments that would trigger a Centaur explosion. This was assumed to lead to large

overpressures and impulses at the location of the RTGs. As the Challenger accident demonstrated, the IUS would not contribute to the accident environment initiated by ET failure in flight. Furthermore, the ET failure resulted in a vapor cloud burning of the hydrogen propellant leading to modest overpressure and impulse.

Nevertheless, there are still accident environments that could threaten the RTGs in the STS/IUS cases. In general, the kinds of environments analyzed to date are blast overpressures and high-velocity motor casing fragments. Based on the RTG safety verification test data (see Ref. 25), no environments have been identified which indicate overpressures at the location of the RTGs that could cause a release of RTG fuel material.

Mitigating Measures

For the STS/IUS configuration, two types of mitigating measures can be considered: additional protective shields or containers to protect the RTGs in accidents, and radiological contingency planning to mitigate the consequences if an accident occurred.

The nuclear material is shielded in the current design of the GPHS/RTG and safety verification test data show the design can withstand and successfully contain fuel over a broad range of potentially hostile circumstances (e.g., reentry ablation, overpressure, etc.). Nevertheless, in the wake of the Challenger accident, NASA conducted a design study of an additional, full-enclosure shield (Ref. 18). After cancellation of the Shuttle-Centaur, this study was continued for the STS/IUS configuration. For this latter case, the study considered the primary threat to be from high-velocity fragments due to, for instance, an SRB rupture during the ascent phase.

An additional full-enclosure shield could provide additional protection from fragments. However, a full enclosure shield could compromise the fundamental design of the GPHS/RTG by adding considerable weight and reducing drag. Thus, in an inadvertent reentry, the shield would lead to an increased ballistic coefficient, higher terminal velocity, hard landing, and a potential large local release of fuel. Therefore, since the additional shielding would add minimal protection, but would add risk in the event of reentry, NASA has decided to maintain the baseline GPHS/RTG configuration with no full enclosure shield.

For missions involving space nuclear power, comprehensive radiological contingency plans must be developed to address all launch/landing phase accidents involving the RTGs and RHUs. These plans are developed through the combined efforts of various government agencies, including NASA, DOE, the Department of Defense (DOD), the Environmental Protection Agency (EPA), and the State of Florida, and are formulated to conform to the Federal Radiological Emergency Response Plan (FRERP) (Ref. 23). These plans will be updated for the Galileo and Ulysses missions based on the results of the new FSAR and SER. Development and implementation of these plans will ensure the availability of appropriate response personnel, equipment, facilities, and procedures in the event of a launch accident.

The primary objectives during the early phases of an accident are to determine whether a release of radioactive materials has occurred, to assess

and characterize the extent of the release, to predict the propagation of the released material, and to formulate/recommend mitigating actions to safeguard humans and the environment from the consequences of the release. These objectives will be achieved through the evaluation and analysis of real-time data provided by mobile field monitoring teams and ground air-sampling stations, airborne monitoring and surveillance aircraft, ground and airborne meteorological stations, and computerized dispersion modeling.

Follow-on objectives would be to isolate contaminated areas, recover the fuel materials, and decontaminate and/or recover affected areas, facilities, equipment, and properties.

4.5.2.3 VEEGA Trajectory Implications

Use of the STS/IUS will require the Galileo spacecraft to execute one Venus and two Earth flyby gravity assists (VEEGA trajectory) to gain sufficient kinetic energy to get to Jupiter. During the second Earth flyby, the spacecraft will travel at 14.2 km/s and its closest approach may be some 300 km in altitude above the surface of the Earth.

Over the last year, JPL, which developed the Galileo Mission, has conducted an extensive study to identify and determine the likelihood of mission accidents or failures that could cause the Galileo spacecraft to impact the Earth during one of the spacecraft's two Earth flybys. As a result of this study (Ref. 29), a spacecraft design modification was made to decrease the probability of a spacecraft failure leading to Earth-impact. With the implementation of this modification, the study determined the overall probability of an Earth-impact accident to be 5×10^{-7} .

This result, while considered conservative, does not address the issue of whether or not or to what extent a release of Plutonium-238 can occur in the event of an Earth reentry accident; this issue will be addressed in the Final Safety Analysis Report (FSAR) for the Galileo Mission and the Galileo Mission EIS (Tier 2).

There are three types of mission accidents or failures which could lead to inadvertent reentry during a VEEGA flyby. They are: (1) navigation dispersions, (2) spacecraft failures, and (3) ground operations errors. For each of these, a range of events were defined and analyzed to quantify the contribution of each to the overall probability of Earth-impact and to assess spacecraft and/or mission design changes that could lower the probability of an Earth reentry accident. The study results are summarized in the following subsections.

Navigation Errors

All Galileo spacecraft maneuvers will be designed subject to the constraint that the probability of the spacecraft ending up on an Earth-impacting trajectory (as a result of the maneuver) will be less than or equal to 10^{-6} . This is accomplished by biasing the spacecraft's aimpoint away from the Earth. (The "aimpoint" is the location at which the spacecraft would fly by the Earth on any given trajectory if it were allowed to continue from that point with no further maneuvers.)

In assessing this strategy, JPL has determined that navigation dispersion errors do not effect the capability to perform a recovery maneuver from an Earth-impacting trajectory. When this capability is accounted for in the analysis, the probability of Earth-impact due to navigation dispersions has been determined conservatively to be 10^{-10} on each of the two Earth flybys.

Spacecraft Failures

JPL has evaluated many types of failure modes that might have the potential to place the Galileo spacecraft on an Earth-impacting trajectory during either of the two Earth-flybys. Table 4-1 summarizes the probability estimates for these failure modes. Only three have been determined to represent even a remote threat of Earth-impact. Of these three, concerns about Retro-Propulsion Module Overpressure Conditions have already led to the implementation of a spacecraft design change (see below).

- Retro-Propulsion Module Penetration By a Micrometeoroid - The probability of this failure mode occurring and leading to Earth-impact is 4×10^{-7} . The sequence of events required to lead to Earth-impact is as follows: 1) a micrometeoroid (of sufficient size and velocity) penetrates the protective layers of the existing micrometeoroid shield with sufficient energy to cause a tank to rupture; 2) the rupture of the tank alters the velocity of the spacecraft in the direction and with the magnitude necessary to place the spacecraft on an Earth-impacting trajectory; and 3) all attempts to recover the spacecraft from this trajectory fail.
- Thrusters Stuck Open or Shut - The probability of this failure mode occurring and leading to Earth-impact is 6×10^{-9} . The sequence of events required to lead to Earth-impact is as follows: 1) an electronics failure causes one or more of the spacecraft's propulsion thrusters to stick after a maneuver has been completed; 2) during the next maneuver an unexpected change in velocity occurs which alters the spacecraft's trajectory differently than intended; 3) this trajectory is one that will lead to Earth-impact; and 4) recovery attempts fail.

This type of failure would only result in small perturbations in the spacecraft's trajectory because there are valves upstream of the thrusters in the propellant lines that will be commanded closed either by automatic spacecraft fault protection software or by command at the end of the maneuver. Moreover, there are two independent thruster systems which provide the capability, in the event of a failure, to shut down one system and accomplish the required maneuver with the second system.

- Retro-Propulsion Module (RPM) Overpressure Conditions - The probability estimate for this failure mode leading to Earth-impact is 3×10^{-9} . The low probability for this failure mode results from having modified the pressure relief valve system on the spacecraft's propellant tanks to avoid the possibility of a propellant tank rupture. The sequence of events required for this failure mode to lead to Earth-impact is as follows: 1) at least two independent failures occur which lead to the inability to

TABLE 4-1: PROBABILITY OF VEEGA EARTH-IMPACT BY
SPACECRAFT/MISSION ACCIDENT/FAILURE MODE

Failure Mode	Probability of Failure Occurring that Places Spacecraft on an Earth Reentry Trajectory and No Recovery can be Made
Spacecraft Failures Due to Micrometeoroid Impact	4×10^{-7}
Thrusters Stuck Open or Shut	6×10^{-9}
Retro-Propulsion Module Overpressure Conditions	3×10^{-9}
Other Failures	1×10^{-9}
Ground Operation Errors	1×10^{-7}
Total Probability	5×10^{-7}

command and control the spacecraft; 2) as a result of this, the spacecraft's orientation to the sun changes such that the propellant tanks are heated causing a rise in pressure inside the tanks; 3) the pressure relief valve system on one tank fails; 4) the pressure increase leads to a tank rupture; and 5) the trajectory change resulting from the rupture is one that leads to Earth-impact rather than the more likely outcome of moving the spacecraft even farther away from Earth.

- Other Failure Modes - Six additional spacecraft failure modes have been determined to represent a remote threat of placing the spacecraft on an Earth-impacting trajectory with no chance of recovery: Command Data Subsystem (CDS) or Attitude and Articulation Control Subsystem (AACS) Software Errors; AACS/CDS Memory Chip Failure; Uplink Command Errors; Spacecraft Structural Failures; Radiation, Cosmic Ray, and Single Event Upset Effects; and Spacecraft Charging Due to the Near Earth Environment. None of these failure modes are associated with a credible series of events that would result in Earth-impact.

Ground Operations Errors

The total probability of this failure mode occurring and leading to Earth-impact is 1×10^{-7} . The sequence of events required to lead to Earth-impact is as follows: 1) an error is made in preparing a command sequence for the spacecraft; 2) the error is not detected during the command sequence approval process and is transmitted to the spacecraft; 3) the error causes an anomalous thruster firing; 4) as a result, the spacecraft trajectory changes; 5) this trajectory is one that will lead to Earth-impact; and 6) recovery attempts fail.

In the remote circumstance that events 1 to 5 did occur, the probability of recovery from this failure mode is high because it does not involve any spacecraft failure.

Implication of VEEGA Trajectory Earth-impact Probabilities

While these estimates are considered conservative estimates of the probability of Earth-impact, they do not address the issue of whether or not or to what extent a release of Plutonium-238 can occur in the event of Earth reentry; this issue will be addressed in the Galileo Mission EIS (Tier 2).

Still, in the remote instance of reentry, preliminary analysis by GE indicates that the RTG heat source modules or graphite impact shells would survive reentries. For a small band of shallow angles (between 0 degrees and about -5 degrees), the modules will escape the Earth entirely. Under some reentry conditions the aeroshell has been predicted to fail, releasing the impact shells containing the fueled clads. In some cases the iridium clads are predicted to melt. Almost all impacts would be on water, soil, or sand for which there is a high probability of containing the fuel. A small percent of the impacts would involve a hard surface, and hence a localized release of fuel. A comprehensive test and analysis program to produce an updated prediction of the module performance in a VEEGA reentry

produce an updated prediction of the module performance in a VEEGA reentry has been initiated by DOE.

4.5.2.4 Delay Alternative Launch Configurations

With a delay, launch of Galileo could take place with the STS/IUS or with the Titan IV/IUS configuration. There would be no difference between the proposed action or a delayed launch in terms of potential STS/IUS accident considerations. This section addresses comparisons of accident considerations between the STS/IUS and the Titan IV alternatives. The discussion generally will apply to both Galileo and Ulysses except for the VEEGA reentry scenario, which applies only to Galileo.

In an overall sense, the SRBs, which all available systems (STS and Titan IV) use, by experience have a higher empirical probability of an accident than the liquid propellant systems. In view of the extensive redesign and testing program in the wake of the Challenger accident, it is reasonable to presume that the SRBs to be used in the STS will be more reliable than those previously used.

Available Information

The detailed definition of the Titan IV accident environments will be complete prior to the preparation of the Tier 2 EIS for the Galileo mission. These detailed environments will be used as an input to the analysis that will evaluate the risks associated with the mission if the Titan IV is used as the launch vehicle.

The preliminary information being analyzed from the Titan 34 D-7 accident is relevant to consideration of Titan IV accidents.

The RTG test information described in Section 4.1.2 is applicable to a Titan IV configuration and will be used in evaluating the response of RTGs to Titan IV accidents.

Titan IV/IUS Accidents

The approach taken in this assessment is to identify design features of the Titan IV/IUS configuration that are relevant in identifying differences between Titan IV/IUS and STS/IUS accident scenarios and to discuss their implications on RTG fuel releases.

The vertical stack of a Titan IV vehicle with the spacecraft and RTGs at the top of the stack, as shown in Figure 2-13, moves the RTGs farther away from liquid propellant tanks and potential liquid propellant centers of explosion than is the case with the STS/IUS with reference to the STS ET. The Titan IV liquid fuel (Aerozine-50 and nitrogen tetroxide oxydizer) has a lower energy density than the liquid hydrogen/liquid oxygen fuel and oxydizer of the STS. Therefore, any explosion of the Titan IV liquid propellants would be expected to be less severe on an RTG than an explosion of Shuttle ET liquid propellants.

The threat of SRB casing fragments is also small because the SRBs are well removed from the RTGs. Observations of high-speed films of the Titan IV explosion of one SRB and the destruct of the other clearly showed that SRB fragments would miss the RTGs, had RTGs been on that flight. Only a failure of an SRB in the head-end of the booster could produce fragments directed toward the RTGs.

An early ascent failure (over land) might cause an on-end impact of an intact RTG sufficient to release some RTG fuel. Such a release would be small and likely would be localized to near the impact spot due to the absence of an explosion fireball at the point of release.

Intact high-speed impact of a Titan IV/IUS is less likely than for the STS/IUS, since the vehicle has an automatic inadvertent separation destruct mechanism.

Consideration of on-orbit, trajectory insertion and VEEGA accidents for the Titan IV/IUS configuration are similar to those for the STS/IUS.

Mitigating Measures

The principal mitigating measures for the launch configurations available under the delay alternative are the protective shields or barriers for the RTGs and emergency planning. The radiological contingency planning measures would be similar for all of the alternatives and were discussed in Section 4.5.2.2.

For an expendable launch vehicle such as the Titan IV/IUS, the most reasonable additional RTG protection design probably would be a fragment barrier. The design concept would be an energy-absorbing structure mounted between the RTGs and the IUS. Because the fragment barrier design would not fully enclose the RTGs, protection from a near-pad ground impact would be limited. Mission performance considerations would require that the fragment barrier be jettisoned prior to the Earth-Orbit-Escape Phase, thereby providing no additional protection from an Earth-orbit explosion followed by reentry.

4.5.2.5 Implications of Unavailable Information

The purpose of this EIS is to present sufficient information to enable a choice among the alternatives presented in Section 2 (i.e., continue spacecraft modifications, delay Galileo modifications, cancel either mission, or cancel both missions). The proposed action, to continue Galileo spacecraft modifications, has no direct adverse environmental impacts. Therefore, enough information is available to enable that decision to be made.

In this EIS, the launch implications are treated in a preliminary fashion, recognizing that additional NEPA related documentation will be prepared for Ulysses and as part of the Galileo Mission Tier 2 EIS.

The detailed safety and environmental analyses and safety verification test program for the STS/IUS are underway but not yet complete. Therefore, detailed, quantitative information on environmental consequences and probabilities are not yet available.

In the absence of the Centaur upper stage, the environments of primary interest are due to motor case fragments and VEEGA reentry. For instance, the case of intact high-velocity ground impact of the Shuttle launch system was deemed not credible in the earlier analysis because of range destruct capability and the potential for vehicle break-up. The concern is that intact impact could lead to a severe explosion if the vehicle were not subject to prior range safety destruct action.

As stated earlier, an environment of primary interest is that of high-velocity fragments due to solid rocket motor rupture. The SRB motor casing is approximately one-half inch thick (12.5 mm) and is a tool steel alloy. Although the impact on steel will be different from aluminum used in the earlier tests, one would also expect, based upon recent preliminary analyses, that fragment (flyer plate) velocities also will be lower than those used in the earlier tests. Preliminary results of the safety verification test program show that the RTG will withstand SRB side-on fragment impact at 212 m/s (690 f/s) with no release of nuclear materials. Solid rocket motor fragments will be treated in depth in the STS/IUS safety analysis and in the Galileo Mission EIS (Tier 2).

Another scenario under particular discussion is the survivability of the RTG, during abort crash landing (e.g., a "wheels up" landing or "ocean ditch" landing). The Shuttle is designed to coast unpowered to its routine landing but has relatively low lift-drag ratio compared to conventional aircraft. Based upon comparisons with aircraft flight recorders that survive many aircraft crashes, and considering the demonstrated ability of the GPHS/RTG to survive impacts at 54 m/s (175 f/s), it is believed that the RTG would survive a crash landing or ocean ditch, but this scenario also is receiving further study.

Although final numerical accident probabilities are not yet available for the Galileo mission, discussion since the Challenger accident has focused on probabilities to be assigned to the launch vehicle systems. Based upon prior launch vehicle experience, the highest empirical accident probabilities are associated with the SRBs. Since both the STS and the alternative Titan IV expendable launch vehicle systems use SRBs during the earliest ascent phases, one could conclude that the overall probabilities would be of the same order of magnitude.

It does not appear that information unavailable at this time is of sufficient nature to preclude or obviate a decision among the alternatives presented in Section 2.

4.6 SUMMARY OF ENVIRONMENTAL CONSEQUENCES

The environmental consequences that could result from the implementation of each of the programmatic alternatives available to NASA are expected to be similar. The specific act of implementing any of the choices has no near-term environmental impact. However, there are significant programmatic, economic, scientific, and geopolitical consequences associated with the alternatives.

If the modifications of the spacecraft were delayed a year or more until completion of the FSARs and the additional NEPA related documentation, there would be major programmatic impacts. Attempting to retain critically skilled personnel on a standby basis would be inordinately expensive. On the other hand, releasing such personnel and later attempting to hire replacements undoubtedly would lead to delays that would threaten the 1991 launch opportunity. Although NASA could regain the skills, NASA would lose the experience base of the current staff.

Furthermore, additional delay could add risk to the success of the mission. To minimize system deterioration, the spacecraft would have to be serviced periodically. Such service would add expense.

Finally, further delay would reflect adversely on the U.S. program vis-a-vis the space programs of eastern bloc nations. The Soviets, for instance, have launched a mission to the Martian moon Phobos during 1988. This is in sharp contrast to the NASA program, which has announced a series of delays and deferrals.

The only significant potential environmental consequences are associated with launch. Therefore, this EIS has treated the launch implications in at least a preliminary way, recognizing that there will be a subsequent decision made in the summer of 1989 for Galileo and in 1990 for Ulysses. NASA will prepare additional NEPA related documentation based on information currently being developed for the FSAR. The environmental impacts of normal launches are associated with the STS or Titan IV vehicles and would be similar to other NASA launches of non-RTG missions. The environmental consequences of accidents will be the subject of the additional NEPA related documentation currently under preparation.

4.7 ADVERSE ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

There are no unavoidable adverse environmental impacts associated with the proposed action or the alternatives.

4.8 RELATIONSHIP BETWEEN SHORT-TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

There are no impacts on the maintenance and enhancement of the long-term productivity of man's environment as a result of the proposed action. The activities associated with the proposed action are all occurring in an existing building at the Jet Propulsion Laboratory.

4.9 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

The modifications required for the proposed action involve the application of thermal blankets to a portion of the spacecraft and the modification of hardware for the mating of the spacecraft to the upper stage. These resources represent insignificant commitments of readily available resources.

5. LIST OF PREPARERS

- 5.1 NASA HEADQUARTERS
Washington, DC
- 5.2 JET PROPULSION LABORATORY
Pasadena, CA
- 5.3 SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
Washington, DC and McLean, VA

6. AGENCIES AND INDIVIDUALS CONSULTED

This Supplemental Draft Environmental Impact Statement (EIS) was made available for review for a period of 45 days by Federal, state, and local agencies and the public, as applicable. All information received was considered during preparation of the Final EIS. Comments were solicited from the following:

Federal Agencies:

- Council on Environmental Quality
- U.S. Department of the Air Force
- U.S. Department of Commerce
- U.S. Department of Defense
- U.S. Department of Energy
- U.S. Department of Health and Human Services
- U.S. Department of Transportation
- U.S. Environmental Protection Agency
- National Academy of Sciences
- Nuclear Regulatory Commission
- Office of Management and Budget

State Agencies:

- Florida Department of Environmental Regulation
- East Central Florida Regional Planning Council
- Intergovernmental Coordination--Office of the Governor of California
- State of New Mexico

Local Agencies:

- Brevard County: Board of Commissioners
- Economic Development Council
- Planning and Zoning Department
- Canaveral Port Authority
- Cape Canaveral, City of
- Cocoa, City of
- Titusville, City of

Organizations:

- Air Pollution Control Association
- Center for Law and Social Policy
- Common Cause
- Concern, Inc.
- Environmental Policy Institute
- Federation of American Scientists
- Florida Defenders of the Environment
- Natural Resources Defense Council
- Physicians for Social Responsibility
- SANE
- Sierra Club
- Sierra Club, Florida Chapter

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APPENDIX B
GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ASE	airborne support equipment
BOM	beginning of mission
Ci	Curie
cm	centimeter
DOD	Department of Defense
DOE	Department of Energy
EIS	Environmental Impact Statement
ELV	expendable launch vehicle
EOM	end of mission
EPA	Environmental Protection Agency
ESA	European Space Agency
ESMC	Eastern Space and Missile Center
f/s	feet per second
FC	fueled clad
FRERP	Federal Radiological Emergency Response Plan
FSAR	Final Safety Analysis Report
FWPF	fine weave, pierced fabric
g	gram
GGs	Global Geospace Science
GIS	graphite impact shell
GPHS	general purpose heat source
HGA	high gain antenna
INSRP	Interagency Nuclear Safety Review Panel
IUS	Inertial Upper Stage
JOI	Jupiter orbit insertion
JPL	Jet Propulsion Laboratory

ABBREVIATIONS AND ACRONYMS (CONTINUED)

JSC	Johnson Space Center
KSC	Kennedy Space Center
km/s	kilometers per second
LANL	Los Alamos National Laboratory
lbf	pounds of force
LES 8/9	Lincoln Laboratory Experimental Satellite 8 and 9
LWRHU	Light Weight Radioisotope Heater Unit
m/s	meters per second
MET	mission elapsed time
MHW	multihundred Watt
mi/s	miles per second
MMH	monomethyl hydrazine
N	Newton
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
OMS	Orbital Maneuvering System
OSTP	Office of Science and Technology Policy
PAM	Payload Assist Module
ppm	parts per million
PSAR	Preliminary Safety Analysis Report
psi	pounds per square inch
RHU	radioisotope heater unit
Rj	Jovian radii
RPM	retropulsion module

ABBREVIATIONS AND ACRONYMS (CONTINUED)

RTG	radioisotope thermoelectric generator
SAR	Safety Analysis Report
SER	Safety Evaluation Report
SNAP	space nuclear auxiliary power
SRB	solid rocket booster
STS	Space Transportation System
USAR	Updated Safety Analysis Report
VAFB	Vandenberg Air Force Base
VEEGA	Venus-Earth-Earth-Gravity-Assist
W	Watt

APPENDIX C

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APPENDIX D
RESPONSES TO PUBLIC REVIEW COMMENTS

D.1 INTRODUCTION

The purpose of this section is to address comments received in response to the draft environmental impact statement (DEIS). The DEIS was made available for public review in November 1987, and the comment period was open for a period of 45 days.

Letters that transmitted written comments to NASA on the DEIS were received from several Federal, state, and local organizations. Complete copies of these comments are presented in the following pages, and the comments are marked and numbered for identification purposes.

Where appropriate, when a change in the DEIS text was not required, a NASA response is provided in this section next to the text to which it applies. Where changes in the text were appropriate, such changes have been noted.

D.2 RESPONSES TO COMMENTS

The following pages provide specific responses to comments on the DEIS received from the following organizations:

- U.S. Air Force
- Committee to Bridge the Gap
- U.S. Environmental Protection Agency
- Christic Institute
- State of Florida, Office of the Governor.



DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON, D.C.
20332-5000

20 DEC 1997

Mr. M. Peralta
Acting Associate Administrator
for Management
National Aeronautics and Space Administration
Washington, DC 20546

Dear Mr. Peralta

We have reviewed the Supplemental Draft Environmental Impact Statement for the Galileo and Ulysses Missions and have no comments. Thank you for affording us the opportunity to participate in the review process.

Response:
No response is required.

Sincerely

Ewing J. Bedner

ERWIN J. BEDNER
Deputy Chief, Environmental Division
Directorate of Eng & Svcs

COMMITTEE TO BRIDGE THE GAP

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December 24, 1987

Dr. Dudley G. McConnell
Code EL
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Dr. McConnell:

Enclosed please find our comments on the Supplemental Draft
Environmental Impact Statement for the Galileo and Ulysses Missions.

Yours sincerely,

Norm Aftergood
Steven Aftergood
Executive Director

December 24, 1987

Committee to Bridge the Gap
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SUBMITTED TO THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
UNITED STATES OF AMERICA

On the November 1987

"Supplemental Draft Environmental
Impact Statement for the Galileo
and Ulysses Missions"

PUBLIC COMMENT

Introduction

The new launch configuration for the Galileo mission described in the Supplemental Draft Environmental Impact Statement (EIS) eliminates the hazards associated with launch of the liquid-fueled Centaur G upper stage rocket. However, it introduces new risks in connection with the proposed Venus-Earth-Earth-Gravity-Assist (VEEGA) trajectory, which involves two Earth flybys.

As discussed below, we believe that the EIS provides insufficient information to assess the magnitude of these risks or to demonstrate the necessity of the VEEGA trajectory.

Discussion: Reentry Consequences

The most significant changes introduced by the proposed Galileo reconfiguration, from the point of view of environmental impact, are the new risks associated with high-speed accidental reentry during Earth flyby and the potential release of plutonium-238 into the environment. Yet this scenario is not seriously addressed by the EIS.

The notice of "Intent to Prepare a Supplemental Environmental Impact Statement (EIS): Galileo and Ulysses Missions"¹ stated:

In the event of a launch accident, there are potential adverse environmental effects associated with the possible release of plutonium-238 from the KRGs. The potential effects which will be considered in preparing the Supplemental Draft EIS include risks of: ...local land area contamination by plutonium-238; adverse health and safety impacts;...

In fact, however, the Supplemental Draft EIS does not consider launch accidents or flyby reentry in more than a cursory fashion, deferring such matters to a later date.² Instead, the present EIS limits discussion to the consequences of four alternative administrative decisions. Since these decisions do not, strictly speaking, involve a launch decision, they have no environmental consequences!

Nevertheless, the proposed action does represent a tentative commitment to, and investment in, the VEEGA trajectory, in the form of modifications of spacecraft hardware for the Galileo mission. Before proceeding very far

1. 52 Federal Register 614, 615, January 7, 1987

2. "The environmental consequences of accidents will be the subject of the additional updated EIS currently under preparation." Supplemental Draft EIS p. 4-23.

Response 1:

The text has been revised in response to this comment. The revised text is found in new Subsection 4.5.2.3 - VEEGA Trajectory Implications (page 4-18) which has been prepared specifically in response to this and other VEEGA comments.

Response 2:

Launch accidents and fly-by reentry are addressed in Section 4.5.2 of the EIS. The Galileo Missions EIS (Tier 2) to be prepared following the completion of the Final Safety Analysis Report, will provide detailed analyses of launch accidents and associated safety issues. The present EIS does not preclude a later decision to delay or cancel the launch of the Galileo and Ulysses missions.

Refer to the response to Comment 1, with respect to flyby-reentry.

with such modifications, it would have been desirable to determine whether the probability and consequences of flyby reentry are acceptably small. The EIS does not provide sufficient information to make this assessment, relying instead on expressions of confidence without data or documentation to back them up. (See specific comments below.)

Discussion: Alternatives to the VEEGA Trajectory

The 1986 Galileo mission intended use of the Centaur G upper stage rocket, allowing a direct trajectory to Jupiter lasting just over two years. The reconfigured mission described in the EIS, using a solid fueled Inertial Upper Stage (IUS), would instead require six years in flight. The adverse consequences of the proposed change include delayed scientific returns, longer unattended flight time between launch and achievement of mission objectives, increased risk of collision with meteoroids and space debris and, perhaps most important, the new risk of trajectory deviations leading to high-speed atmospheric reentry during Earth flyby.

The EIS takes for granted that VEEGA is the trajectory of choice and does not acknowledge or consider alternatives. Yet, as stated above, it does not provide a sufficient basis to conclude that the risks of flyby reentry are acceptably small. Even though the proposed action discussed by the EIS does not involve a launch decision or a firm commitment to VEEGA, it does involve an investment in spacecraft modifications in favor of VEEGA that may make any possible alternatives less likely.

The virtual silence of the EIS concerning alternatives to VEEGA leaves us with many unanswered questions, including the following:

- (a) Planetary configurations in 1992 would have allowed use of an IUS to launch Galileo without any Earth flyby, using instead a Mars flyby.³ When is the next such planetary configuration?

3. see "Environmental Impact Statement for the Proposed Centaur Upper Stage for Use with Space Transportation Systems," Final Statement, March 1985, pp. 111, 45.

Response 3:

Refer to the response to Comment 1.

Response 4:

The 1982 Galileo mission design presumed a 3-stage IUS for the Earth-Mars-Jupiter trajectory. The next Earth-Mars-Jupiter opportunity, compatible with the launch capability of an STS and three-stage IUS, is in 2031.

The STS does not have the capability of launching Galileo with any booster added to the two-stage IUS; nor would such a configuration allow Galileo to fly directly from Earth to Jupiter. The three-stage IUS, which was cancelled in 1981 due to cost and technical problems, would require approximately 65,000 pounds of Shuttle cargo capacity - 15,000 pounds more than the Shuttle's current 50,000 pound cargo weight capability.

No changes to the text were made in response to this comment.

(b) If Galileo, like Ulysses, were to use a three-stage solid booster (i.e., the two-stage IUS plus the PAM-S Payload Assist Module instead of the IUS alone), would this make a direct trajectory possible? Is the Space Transportation System (i.e., the space shuttle) capable of launching Galileo with a three-stage booster?

Response 5:

The additional energy afforded by a PAM-S would be far less than what is needed to allow Galileo to fly a direct trajectory to Jupiter. Because the Galileo spacecraft has a much larger mass than the Ulysses spacecraft (i.e. approximately 6,000 lbs. for Galileo compared to approximately 800 lbs. for Ulysses), the PAM-S configuration for Galileo would require approximately 54,000 lbs. of Shuttle cargo capacity; this requirement exceeds the current 50,000 lb. Shuttle capability. Even if the configuration were feasible, a direct trajectory would still not be possible; a single Earth flyby would still be required. Moreover, to make such a mission feasible, (1) the size of the Galileo spacecraft retro-propulsion module would need to be increased, (2) mission science would have to be significantly reduced, (3) the launch vehicle performance margin would be so small that it would threaten successful implementation of the mission.

The STS does not have the capability of launching Galileo with any booster added to the two-stage IUS; nor would such a configuration allow Galileo to fly directly from Earth to Jupiter. The three-stage IUS which was canceled in 1981, would require approximately 65,000 pounds of Shuttle cargo capacity, which is 15,000 pounds more than the Shuttle's current 50,000 pound cargo weight capability, therefore exceeding the lift capability of the Shuttle for launching Galileo.

No changes to the text were made in response to this comment.

(c) If the weight of a three-stage booster for Galileo would be excessive, could Galileo be modified to reduce its weight accordingly? (The modifications proposed by the EIS would add weight to Galileo in the form of VEGA-related hardware.)

Response 6:

The weight of Galileo plus the minimal three-stage booster (using a PAM-S) exceeds the STS lift capability by approximately 4000 pounds. It would not be possible to reduce Galileo's weight by 4000 pounds, an amount which represents two-thirds of the weight of the Galileo spacecraft. In contrast, the Galileo weight increase to accommodate the VEGA trajectory is approximately 250 pounds, an amount within the lift capability of the STS.

Moreover, if a three-stage booster were used, (1) the size of the Galileo spacecraft retro-propulsion module would need to be increased, (2) mission science would have to be significantly reduced, (3) the launch vehicle performance margin would be so small that it would threaten successful implementation of the mission.

No changes to the text were made in response to this comment.

(d) The EIS states that if Galileo were launched on a Titan IV rocket with a Centaur upper stage, it could use a single Earth flyby.⁴ Could an additional solid-fueled upper-stage (e.g., the PAM-S) be added on to eliminate the Earth flyby altogether?

Response 7:

Refer to the response to Comment 5.

Specific Comments by EIS Page Number

P. 1-1

"Following the Challenger accident, NASA cancelled the development of the Shuttle version of Centaur (i.e., the Centaur G-Prime) due to safety concerns unrelated to the Galileo and Ulysses spacecraft."

Comment We note, however, that NASA intends to proceed with development of the Centaur upper stage for use with the unmanned Shuttle-C. The explicit purpose of this development is to allow launch of "planetary spacecraft of the Mariner Mark II class."⁵ The Shuttle-C/Centaur is tentatively scheduled for flight testing in 1993 and could be operational by 1994. Thus, in the near mid-term there will be alternative launch modes for planetary spacecraft such as Galileo and Ulysses.

5. See NASA solicitation for a "Centaur Shuttle-C Compatibility Study," Commerce Business Daily, December 11, 1987, p. 1.

P. 2-4

"No combination of launch vehicles presently available to NASA has the capability to place the Galileo spacecraft on a trajectory from Earth directly to Jupiter."

Comment This is a crucial assertion, which ought to be elaborated. As indicated by our questions above about alternatives to VEGA, we are not yet convinced that it is true.

Furthermore, we note that with separate launches of the Orbiter and Probe, Galileo apparently could be placed on a direct trajectory to Jupiter.⁶ This may be an unacceptable alternative for cost reasons (it should be the function of an EIS to weigh such options), but if it is indeed possible, then the cited statement is untrue.

6. This possibility is raised in "Environmental Impact Statement for the Proposed Centaur Upper Stage for Use with Space Transportation System," Final Statement, March 1985, pp. iii, 45-6.

Response 8:

Theoretical estimates do indicate that such a vehicle would equal or exceed the launch capability of the previous STS/Centaur G-Prime and therefore could theoretically be capable of propelling Galileo on a direct trajectory to Jupiter. Unless such a vehicle were available before the period December 1993 to January 1994, Galileo's arrival at Jupiter would be delayed 1.5 to 2 years when compared to the arrival date projected with the 1989 STS/IUS launch. In any case, until a design exists for a Shuttle-C/Centaur, NASA lacks a basis for considering this postulated launch configuration as a feasible alternative to the STS/IUS or Titan IV/IUS.

No changes to the text were made in response to this comment.

Response 9:

Separate launches of the orbiter and probe on direct trajectories to Jupiter would require a Titan IV with a higher performance Centaur booster than currently exists. Additionally, NASA would need to (1) build a second spacecraft for the probe and (2) use an additional STS to power the spacecraft carrying the probe. Separate launches of the orbiter and probe using a Titan IV with the existing Centaur would still require a single Earth flyby for the orbiter.

The text in Section 2.2.2.1, has been modified to reflect this response.

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P. 2-8 "...operational procedures will be developed to minimize the possibility of inadvertent Earth reentry occurring during Earth flybys." (also p. 2-26).

Comment It will be essential for the nature, effectiveness, and reliability of these operational procedures to be spelled out.

10

Response 10:

The trajectory design and navigation planning are being developed consistent with a plan to bias the trajectory during the period of time between launch and the second Earth flyby such that for most of this time, the trajectory, if left to propagate without any further maneuvers, would miss the Earth by at least several thousand kilometers, and in some intervals, by millions of kilometers. The spacecraft is placed on the final trajectory which passes through the required Earth flyby point at 10 days prior to each encounter. Two primary criteria determine this biasing strategy. The first, and generally the one of lesser effect, is to ensure that the probability of an impacting trajectory resulting from any maneuver as a result of statistical navigation dispersions is less than 10^{-6} . Then, considering the probability of being able to take corrective action, given that an impacting trajectory has resulted, the probability of actual entry occurring as a result of navigational dispersions is at least two to three orders of magnitude less than 10^{-6} . For the last maneuver at encounter minus 10 days, the probability of navigating dispersions leading to an impacting trajectory is zero (to within the 10^{-8} capability of the Univac 1100). The second criterion is to minimize or, where possible, eliminate entirely, the risk of an impacting trajectory resulting from spacecraft failures in which spacecraft cause a change in velocity to occur. Details on potential spacecraft failures that could result in a change in velocity, and how these results have influenced the trajectory biasing strategy, are contained in the Earth Avoidance Study Report.

On the final approach to each Earth flyby, additional operational requirements are being imposed to further ensure against re-entry. Continuous tracking by the DSM is planned beginning 35 days prior to each flyby, thus providing around-the-clock doppler and telemetry, and hence near real time evidence of any anomalies. During the period from the last maneuver 10 days out through each flyby, only those spacecraft activities essential for spacecraft operations are planned, such as maintaining solar pointing for thermal control. In this same period, no commands are to be sent to the spacecraft other than any that are essential to operating the vehicle. The premise behind these requirements is that minimum activity on the spacecraft provides the minimum probability of occurrence of unplanned events. During the period of closest approach, the spacecraft will be monitored continuously.

The text in Section 4.5.2.3 was changed in response to this comment.

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p. 2-13 "Fuel cells and batteries cannot meet requirements (4) and (5) [to replace plutonium-powered RTGs] because of their lower power densities relative to weight, thus requiring more launch energy than is available."

Comment Nevertheless, the EIS indicates that batteries would be added in the event of a delayed launch to compensate for degraded RTG power levels.⁷ We would therefore ask, what is the optimum combination of RTGs and batteries that would minimize the use of plutonium-238 while remaining within the available payload weight limits? Would this combination significantly reduce the risks presented by use of RTGs alone?

7. see p. 2-21.

p. 2-13 "RTGs have been used on 22 previous space missions. These applications have included some of NASA's most impressive successes..."

Comment In presenting the history of space nuclear power, it is important to acknowledge that mission failures are not only a hypothetical possibility, but have actually occurred on several occasions, including 3 of the 22 missions mentioned.

In 1964, the Transit 5BN-3 suffered a launch failure and disintegrated at an altitude of 50 km. The 17,000 Curies of plutonium-238 in its SNAP-9A RTG settled to Earth over the next several years, tripling the worldwide inventory of Pu-238.

In 1969, another SNAP RTG failed to achieve orbit and fell into the ocean just off the California coast. It could not be located for 5 months, but was finally retrieved intact.

In 1970, the lunar lander from Apollo 13 burned up in the atmosphere and its SNAP-19 RTG reentered over the south Pacific Ocean where it presumably remains.⁸

Thus, the history of the U.S. space nuclear power program would indicate a probability of accidental reentry of 3 in 22, or more than one chance in ten.

In addition, two Soviet RTGs from failed lunar missions

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Response 11:

The 20 kilograms (kg.) of batteries originally contemplated for the 1991 launch opportunity would have compensated for a loss of approximately only 20 watts in the RTG's power output. This power level is small compared to the 550 watts of power that are provided by the RTGs. The batteries rely on RTG power output to remain charged and are only used for a few hours of peak power demand. The long-term, steady-state power demand requires the existing RTGs.

No changes to the text were made in response to this comment.

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Response 12:

The text has been revised in response to this comment. The revised text is found in Section 4.5.2.1.

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burned up in the atmosphere, releasing measurable amounts of radioactivity in two separate incidents in September and October 62 1969.⁹

9. The latter two incidents, but not the first, are later mentioned in passing in the EIS on page 4-12.

9. see William J. Broad, "Satellite's Fuel Core Falls 'Harmlessly'," New York Times, February 8, 1983, p. C1, C2; Nicholas L. Johnson, "Nuclear Power Supplies in Orbit," Space Policy, August 1986, p. 223, 228; S. Aftergood, "Nuclear Space Mishaps and Star Wars," Bulletin of the Atomic Scientists, October 1986, pp. 40-43.

P. 2-23 "The Titan IV/Centaur launch vehicle is still under development by the Department of Defense (DOD) and will not ... be available to NASA until the 1990s."

Comment Lower on the same page, it states: "Unlike the STS/IUS or Titan IV/Centaur, the Titan IV/IUS is still under development by DOD and will not be available to NASA until the early 1990s." The conflicting statements about the status of the Titan IV/Centaur should be reconciled.

P. 4-1 "An independent safety evaluation [will be] documented in a Safety Evaluation Report (SER)."

Comment The Safety Evaluation Report is prepared by the Interagency Nuclear Safety Review Panel (INSRP), which is largely composed of representatives of the sponsoring agencies, including NASA and DOE.¹⁰ The meetings and deliberations of INSRP are closed. Thus, INSRP and its Safety Evaluation Report are "independent" only of the public!

The EIS notes that INSRP's Draft SER for Galileo and Ulysses is classified.¹¹ We strongly object to this. In our view, nuclear safety is not a proper subject for classification.

All INSRP documents should be immediately declassified. The membership of INSRP should be expanded to include a full spectrum of technical viewpoints, including qualified critics of space nuclear power. INSRP meetings should be opened to responsible public participation. Until this is done, the assertion that INSRP is "independent" is unwarranted.

10. see EIS p. 1-2. 11. p. A-1, References 14.

Response 13:

The text has been revised on pages 2-21 and 2-25 in response to this comment.

Response 14:

The INSRP review process is mandated by the President as specified in National Security Council Presidential Directive 25. The INSRP's primary function is to evaluate the results of the DOE Final Safety Analysis Report (FSAR) and then report their findings back to NASA, DOE and DOD. The NASA and DOE INSRP panel members all report through different and independent line organizations than do the program offices in the two agencies. DOD does not have any programmatic responsibility in the development of either the Galileo or Ulysses spacecraft. Likewise the INSRP subpanel chairpersons have no programmatic affiliation.

No changes to the text were made in response to this comment.

P. 4-11 "GMS modules survive Earth-escape-velocity-reentry ablation, and thermal stress with wide margins."

Comment With the VEGA trajectory, Earth-escape-velocity-reentry is no longer the limiting case. The RTGs must survive flyby-velocity reentry.

- 15

Response 15:

The possibility of Earth reentry from the Galileo spacecraft's VEGA trajectory has been addressed in the Earth Avoidance Report (Ref. 29) prepared by the Jet Propulsion Laboratory. The results of this report are summarized in new subsection 4.5.2.3. The associated response of the RTG's to Earth reentry is currently being analyzed in detail. The final results of this analysis, including an assessment of the risks posed by an Earth-escape-velocity-reentry, will be summarized in the Galileo Mission EIS (Tier 2).

Refer to the response to Comment 1 for text modifications made in response to this comment.

P. 4-17 "Based on preliminary analyses, the Galileo project expects that this accident scenario (flyby reentry) will be deemed not credible."

Comment What the Galileo project "expects" about what "will be deemed credible" does not give much useful information. The preliminary analyses should be cited and made available for public review. Otherwise this statement should be deleted.

- 16

Response 16:

Refer to the response to Comment 1.

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P. 4-17

"The chance [of flyby reentry] is remote because spacecraft communication, guidance, and control techniques have advanced greatly over the past 30 years."

Comment This statement is logically incoherent. The advances of the last 30 years have actually created the possibility of a flyby reentry. 30 years ago a flyby trajectory was beyond the state of the art, and the chance of flyby reentry was therefore zero. Advances in technology create the potential for new types of technological failures as well as successes.

Beyond that, the sentence itself and the paragraph it introduces are too vague to be satisfactory. One recalls the statement from the previous Galileo Draft EIS, written before the Challenger disaster, that the risk of plutonium release to the environment "should be small due to the high reliability inherent in the design of the Space Shuttle...."¹²

Positive thinking may be a good thing, but it cannot substitute for rigorous analysis.

12. "Draft Environmental Impact Statement for Project Galileo," September 1983, p. 111.

P. 4-18

"Therefore, the project estimates the chance of inadvertent [flyby] reentry to be less than one chance in a million."

Comment This estimate does not follow ("therefore") from the preceding sentences. The calculation of the one in a million probability should be documented-- or the statement deleted.

Extravagant claims of safety presented without a clear factual basis inspire doubt and suspicion, not confidence.

P. 4-18

"Based on the 1983 PSAR, the consequences of a high-altitude release of fuel are on the order of 10 of the natural background radiation with no measurable effects."

Comment High altitude release or intact reentry are not the only possibilities. The Iridium cladding could protect the PRC through part of the reentry and fall at a low altitude, yielding a much higher localized radioactive release.

Response 17:

Refer to the response to Comment 1.

Response 18:

Refer to the response to Comment 1.

Response 19:

As stated in the response to Comment 1 and Comment 2, the Galileo Mission EIS (Tier 2), to be prepared following the completion of the FSAR, will present detailed data in this regard. That EIS will be available for public review upon request. The present EIS does not preclude a subsequent decision to delay or cancel the launch of Galileo and/or Ulysses.

Conclusion

The objectives of the Galileo and Ulysses missions are clearly worthy of support, and we support them. Furthermore, without being able to endorse the VEEGA trajectory, we favor prudent action to preserve the earliest available launch opportunities for these missions.

We are concerned, however, that the present EIS presents insufficient information to assess accident consequences generally, and the environmental acceptability of the VEEGA trajectory in particular, i.e. whether the probability and consequences of Earth-flyby reentry are acceptably low.

In the event that the risks associated with VEEGA cannot be shown to be insignificant, the question of alternative trajectories would again become important. The EIS leaves us unconvinced that all alternatives to VEEGA have been acknowledged and fully considered.

Response 20:

The text of the EIS dealing with VEEGA trajectory accidents and environmental acceptability has been modified, as indicated in response to Comment 1. With respect to launch accidents and RTG accident consequences, these issues will be addressed in the Galileo Mission EIS (Tier 2). That EIS will follow the Final Safety Analysis Report for which tests and analyses are presently underway. The present EIS will not preclude a decision to delay or cancel the launch of Galileo and/or Ulysses.

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Respectfully submitted,

Steven Aftergood
Steven Aftergood
Executive Director



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IV
345 COURTLAND STREET
ATLANTA, GEORGIA 30333

December 31, 1987

4-EAB/GJM

Mr. M. Peralta
Acting Associate Administrator
for Management
ATTN: NEQ
National Aeronautics and Space
Administration
Washington, D. C. 20546

Subject: Supplemental Draft Environmental Impact
Statement for the Galileo and Ulysses Missions
EPA Log No.: DE-MUS-EI2001-00

Dear Mr. Peralta:

Pursuant to the Environmental Protection Agency's responsibilities under
Section 309 of the Clean Air Act and the National Environmental Policy
Act, we have reviewed the subject document.

Based on our review, we conclude that no significant long-term, adverse
environmental impacts will occur based on the current data base. Hence,
a rating of LO was assigned, i.e., lack of significant objections. However,
we await with interest the detailed analyses and safety verification test
program documentation in the final Safety Analysis Report as well as
publication of the Safety Evaluation Report.

Sincerely yours,

Stephen H. Moore
Stephen H. Moore, Chief
EPA Review Staff
Environmental Assessment Branch

Response:

No response is required.

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CHRISTIC INSTITUTE

Attn: Mr. G. G. McConnell

January 16, 1988

Re: Galileo/Ulysses Supplemental
Draft Environmental Impact
Statement

Mr. Dudley G. McConnell
National Aeronautics and Space Administration
Washington, D.C. 20546

Dear Mr. McConnell:


I am writing regarding the proposed Galileo and Ulysses missions to raise a concern that I suspect has not been raised previously. Because it would not generally be considered within the ambit of an environmental impact statement.

It is my understanding that these missions will use the decay heat from plutonium as an energy source. I am aware that a number of objections were raised about the possibility of an aborted mission contaminating our planet with released plutonium. But I am relatively certain that no consideration has been given to the possibility that this material will contaminate another planet.

Assume for the moment that there are life forms on planets other than our own. Assume also that one of the exploratory rockets is trapped by the gravitational field of that planet. The possibility then exists that the rocket would crash into the capturing planet and release its plutonium load.

I personally do not believe it is fantasy to assume life forms on other planets. I also believe that it is important to our maturing as a species that we take such possibilities into consideration in our space program. Finally, I believe that if we did assume the existence of other life forms in the universe, we would not be sending our deadliest material out to them.

I do not expect these concerns to be given any serious consideration in the decisions on Galileo and Ulysses but thought it was worth raising the issue now, so it can become part of our thinking later.

Sincerely,

Lanny Sinkin
Assistant General Counsel

1324 NORTH CAPITOL STREET N.W. • WASHINGTON, D.C. 20001 • (202) 797-9106

Offices in
Los Angeles • San Francisco • Chapel Hill, NC

Response 21:

As a matter of policy, in its conduct of the U.S. Solar System Exploration Program, NASA continues to give serious attention and consideration to the concern for possible life forms on other planets and bodies. Because of the extreme nature of the physical conditions found on most other planets and bodies in the solar system, and because of the natural prevalence of high levels of radiation in space, NASA's concern has primarily focused on preventing biological contamination from vehicles destined for landings on other planets and bodies in the solar system.

Specifically with respect to the Galileo Mission, NASA policy has taken into account the most recent scientific findings and recommendations of the Space Science Board of the National Academy of Sciences (Ref. 30). Galileo mission operations have been designed to minimize the potential of contaminating any other solar system body that might harbor life, no matter how remote the possibility. The Space Science Board Committee on Planetary Biology and Chemical Evolution assessed the likelihood that Jupiter itself could sustain Earth-type life (Ref. 31); they found the probability to be essentially nil (i.e., probability of growth, <10⁻¹⁴). Nevertheless, during the Galileo mission, it is NASA's intent to avoid placing the spacecraft into an orbit where it could impact Jupiter or any significant known Jovian satellites. One goal of the Solar System Exploration Program is to understand the origin and evolution of the solar system. Thus, NASA wants to learn more about the natural environment, not to alter it.



STATE OF FLORIDA
Office of the Governor
 THE CAPITOL
 TALLAHASSEE, FLORIDA 32399-0001

BOB MARTINEZ
 GOVERNOR

January 22, 1988

Mr. Lewis Andrews
 Code MIG
 National Aeronautic and Space Administration
 Washington, D.C. 20546

Dear Mr. Andrews:

RE: SAI: FL8712010648

Reference your telephone call and in response to your agency's request please be advised that the Supplemental MHS for the Galileo and Ulysses Missions was forwarded to interested state agencies for review. Based on their review we have no comment on this document.

Sincerely,

Walter O. Kolb
 Walter O. Kolb
 Senior Governmental Analyst

NK/ppm

cc: George W. Percy - State Historical Preservation Officer
 Jim Quinn
 Doug Bailey
 John Outland

Response:
 No response is required.

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